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ROLLING REVIEW OF REQUIREMENTS AND STATEMENTS OF GUIDANCE

STATEMENTS OF GUIDANCE

NOWCASTING AND VERY SHORT RANGE FORECASTING (VSRF)

(Submitted by Paolo Ambrosetti (Switzerland))

SUMMARY AND PURPOSE OF DOCUMENT

The document provides detailed information on the current status of the Statement of Guidance for Nowcasting and Very Short Range Forecasting (NVSRF).

ACTION PROPOSED

The Meeting is invited to note the information contained in this document when discussing how it organises its work and formulates its recommendations.

References: Current versions of the Statements of Guidance http://www.wmo.int/pages/prog/www/OSY/GOS-RRR.html#SOG

Appendix: A. Statement of Guidance for Nowcasting and Very Short Range Forecasting (VSRF), new version for approuval

DISCUSSION

Request from Australian Bureau of Meteorology via WMO:

By way of background information, it was pointed out by Tyrone Sutherland from Region IV during ICG-WIGOS that OSCAR does not include requirements for lightning detection (the variable is listed in the database, but with no associated requirement). This makes it difficult for the NMHS's to argue for funding for systems and/or data-buys.

The suggestion made during the Session was to bring this issue to the attention of IPET-OSDE (cc Etienne for this reason).

Actual entry in OSCAR for lightning detection:

Variable N.99 definition (no associated requirements):
Detection of the time and location (latitude, longitude) of lightning events. Accuracy expressed in terms of Hit Rate and False Alarm Rate, which requires predetermination of a specific distance and time tolerance.
Comment:
As proxy of convective precipitation. Also used for information on the evolution of severe storms and tropical cyclones, the Earth electric field and production of NOx.

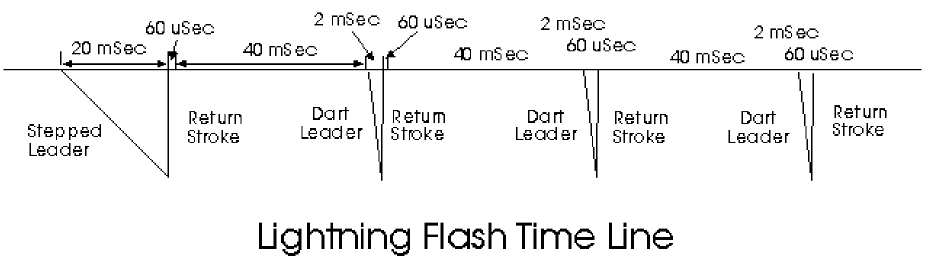
Lightning detection requirements:

Some characteristics of lightning and lighting detection:

There an extensive literature and research on lightning since the 60'. For our need very good overview and up-to-date information are available from EUMETSAT (MTG preparation of the lightning imager instrument) an from the international project CHUVA in Brazil (comparison among several detection technologies).
I tried here to summarize a few facts about lightning and lighting detection, that can be relevant for our needs in OSCAR and SoG:

- Lightning is a complex phenomenon and can be identify or indirectly observed by its generated effects (thunders, optical pulses and a wide range of radio waves).
- The emitted radio waves can be characterized with several attributes: amplitude, sign (positive/negative), number of strokes per flashes, etc.

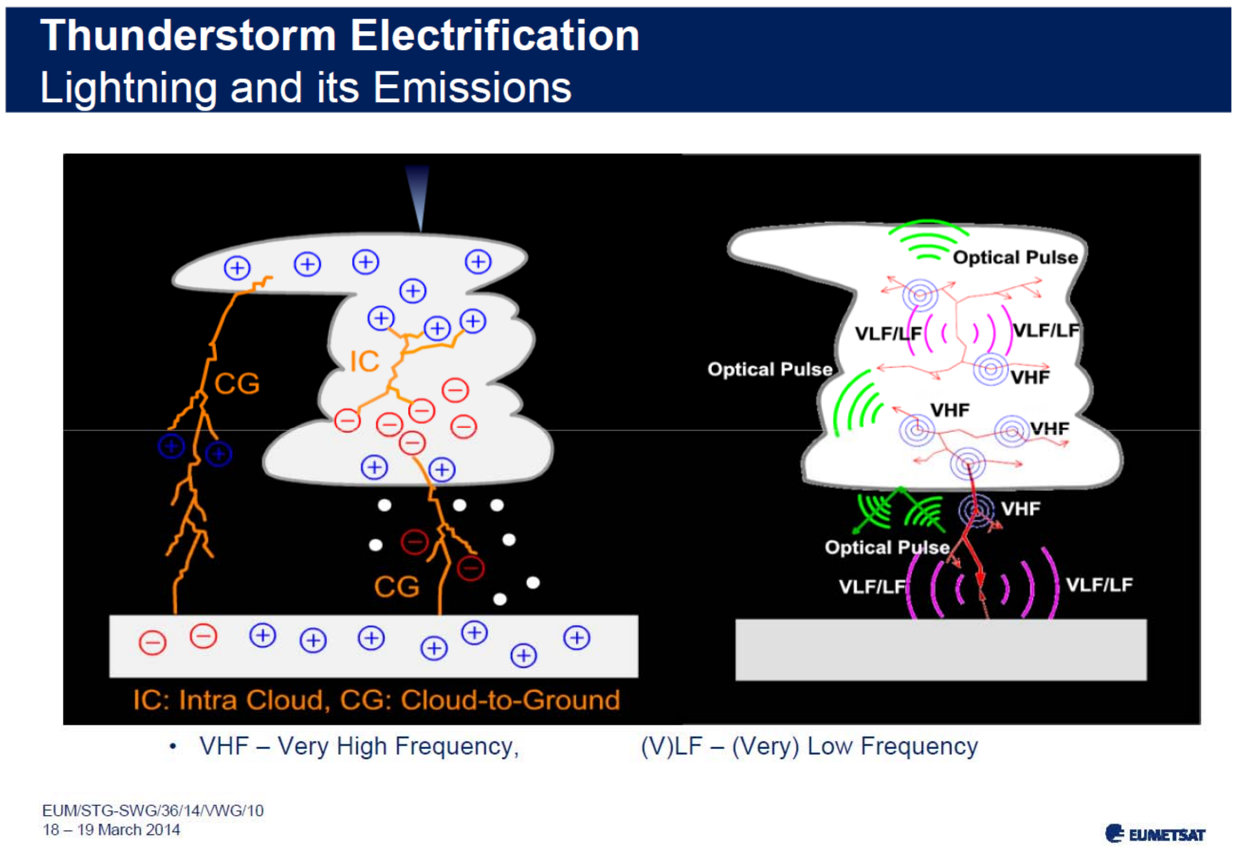
One single flashes is composed from a few strokes in fast sequence. Typical scheme:



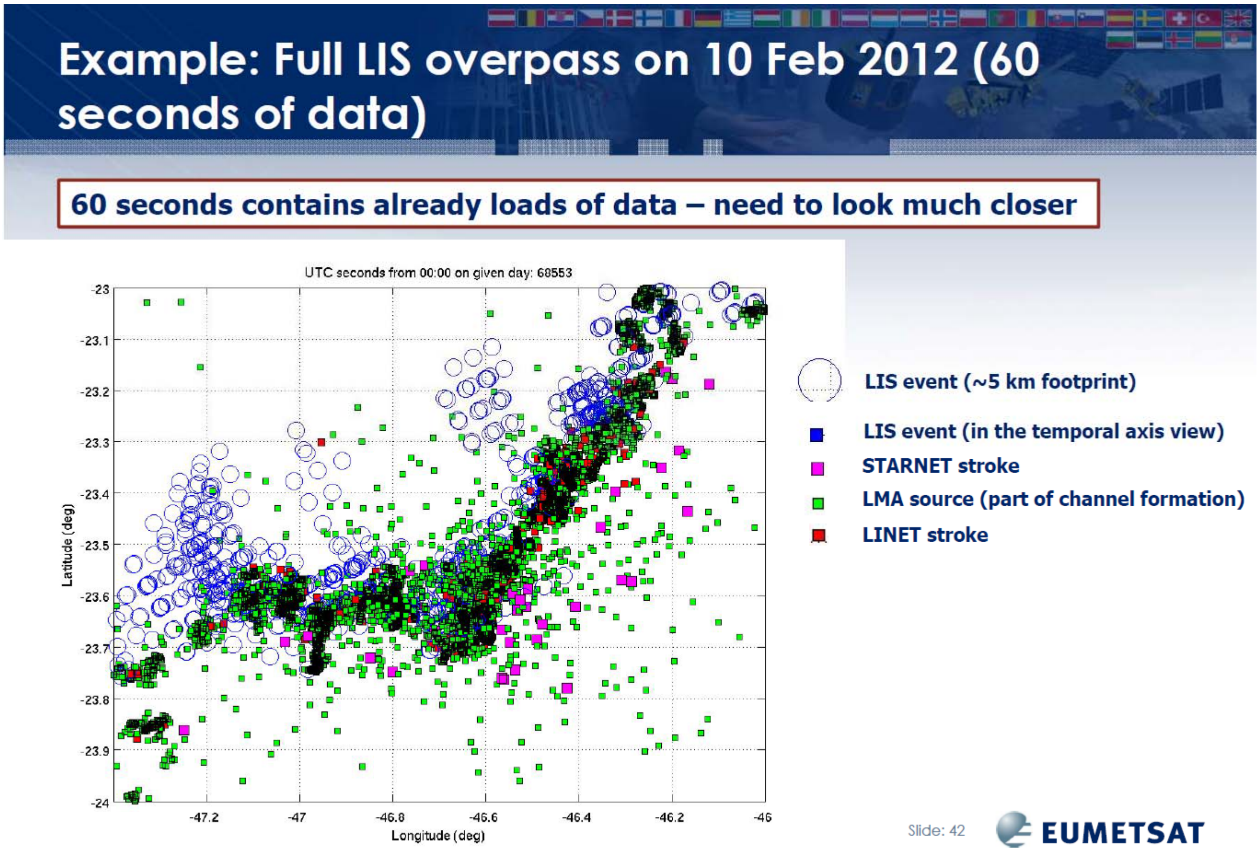
Source: http://home.earthlink.net/~jimlux/lfacts.htm

- Two main categories are used: Intra (and Infra) Cloud and Cloud-to-Ground or the sums of both as Total lightning. Intra Cloud (IC) and Cloud to Cloud (CC) are practically impossible to distinguish by detection. Meteorologically separation is not relevant, for this reason IC and CC are joint considered and called Intra Cloud.

A very good scheme from EUMETSAT documentation:



- The detection efficiency (percent of effectively detected flashes, in particular the Intra Cloud) and position accuracy vary substantially from the detection technology, distance from the antennas, wave frequency and flash frequency/density. For meteorological applications is important that high detection efficiency is achieved for isolated events.
  On the other side false alarm rate must be as low as possible, particularly if these data are ingested in automatic algorithms.
- The position is attributed to a point, but a single flash extend both horizontally and vertically over km and can presents several “branches”. IC horizontal extension can reach several km.
- Comparison between different detection systems and networks can show relevant discrepancies.



- Exact location in space and time of single lighting flashes is usually relevant only for very sensitive places, i.e. Kennedy space centre.
- Several researches showed the importance of the IC lightning for early detection of severe thunderstorm and to better characterize the convection phase.
- SYNOP present/past weather type requires lightning observation in order to identify TS with the correspond codes.
- GEO Satellite lightning data are planned to be disseminated as accumulated flashes products as a lightning density.
- There already some experience in assimilation of lightning data in NWP as hourly accumulated values (i.e. LAPS at FMI).

For meteorological applications no single flash information is therefore necessary, but a good resolution in space and time of the lightning density, i.e. the number of detected flashes in the corresponding time interval and space unit (grid box). These data can be easily combined with other remote sensing data (i.e. radar and satellite) in order to characterize the convection.

For EUMETSAT MTG a L2 product is planned with accumulated recorded lightning flashes over an interval (30”) and for a defined grid (2x2 km).

A good overview paper on Lightning was produced by EUMETSAT:

S.Chauzy et al., On the relevance of Lightning Imagery from Geostationary Satellite Observation for Operational Meteorological Applications

Proposals:

1. With the previous arguments in mind, it is suggested to use in OSCAR as lightning variable the lightning flash "density", i.e. the number of detected flashes in a given time interval and on a grid box (corresponding to the horizontal resolution). Because only some detection instruments can discriminate the CG from to IC data we suggest to introduce two separated variables "Total lightning density" and "Intra Cloud lightning density".

2. The corresponding requirements in OSCAR should be:

Full name	Total lightning density (CG+IC)		
Definition	Total number of detected flashes in the corresponding time interval and the space unit. The space unit (grid box) should be equal to the horizontal resolution and the accumulation time to the observing cycle.		
Measuring Units	Flash number	Uncertainty Units	km
Horizontal Res Units	km	Vertical Res Units	N/A
Stability Units			
Comment:	This variable makes no distinction between Cloud to ground and Intra-clouds lightning flashes.		

For variable: Total lightning density

In application: Nowcasting / VSRF	**Goal**	**Breakthrough**	**Threshold**
Uncertainty	1 km	5 km	20 km
Stability/decade (if applicable)			
Horizontal Resolution	1 km	5 km	20 km
Vertical Resolution			
Observing Cycle	1 min	5 min	30 min
Timeliness	1 min	5 min	30 min

Validated: xx Source: P. Ambrosetti

Comment: in order to combine this data with radar information attributed are proposed. **Confidence:** firm

Full name	Intra-cloud lightning density (IC)
Definition	Number of detected Intra-cloud flashes in the corresponding time interval and the space unit. The space unit (grid box) should be equal to the horizontal resolution and the accumulation time to the observing cycle.

Measuring Units	Flash number	Uncertainty Units	km
Horizontal Res Units	km	Vertical Res Units	N/A
Stability Units			

Comment: This variable considers only Intra-clouds lightning flashes.

Values

For variable: Intra-cloud lightning density

In application: Nowcasting / VSRF	**Goal**	**Breakthrough**	**Threshold**
Uncertainty	1 km	5 km	20 km
Stability/decade (if applicable)			
Horizontal Resolution	1 km	5 km	20 km
Vertical Resolution			
Observing Cycle	1 min	5 min	30 min
Timeliness	1 min	5 min	30 min

Validated:	xxxx	Source:	P. Ambrosetti
Comment: In order to combine this data with radar information similar attributed are proposed.		**Confidence:**	reasonable *(depends on locations)*

3. In order to be consistent with the new proposed OSCAR entries, a few changes in the lightning detection section of the Statements of Guidance (Nowcasting and Very Short Range Forecasting) are proposed.

APPENDIX A

STATEMENT OF GUIDANCE FOR NOWCASTING AND VERY SHORT RANGE FORECASTING (VSRF)

(Point of contact: Paolo Ambrosetti, MeteoSwiss)
(Version with significant revisions of previous SoG by Aurora Bell, February 2012, approved by ET-EGOS-7, May 2012; and further updated by the Point of Contact in June 2013, then approved by the IPET-OSDE Chair)
Revision as April 2014 (highlighted)

Several weather-related decisions require accurate forecasts with high space and time resolution (up to 1 km and few minutes). Sometime this is possible for selected variables and particular weather situations only for very short lead time. Usually forecasts for the next 0-2 hours are called nowcasting (NWC), from 2-12 hours very short-range forecasting (VSRF), and short-range forecasting beyond that; but the capabilities of the different ranges can vary upon variables and weather situations. From the point of view of the users forecast should be “seamless” from the very near time to several days. But the required data and techniques to produce the forecasts vary considerably with the lead time.

Traditionally, nowcasting techniques use extrapolation of observations, applying heuristic rules to modify these observations into the future, like displacing thunderstorm cells by tracking derived vectors. With increasing lead time synoptic rules and numerical weather prediction data take over. Depending on the phenomena, nowcasting and VSRF cover spatial scales from the micro-alpha (hundreds of metres to 2 km) to the meso-alpha (200-2000 km). Temporal scales are from a few minutes to 12 or more hours. At the larger end of the spatial and temporal scales, there is a transition to synoptic scale with phenomena such as extra-tropical and tropical cyclones.

While nowcasting is largely based on observational data, VSRFs are now being generated more and more with high-resolution local area and regional numerical weather prediction models. These models will increasingly be used to provide guidance to meteorologists making detailed nowcasts and VSRFs. It has meanwhile to be mentioned that with higher model spatial and temporal resolutions the needs of good 3D observations increase as well. Nevertheless even high resolution models smooth observation data in the assimilation process losing some information and even with a rapid updating cycle they are “late” for the very beginning of the forecast time. The predictability of an atmospheric phenomenon depends on its lifetime. Since thunderstorms typically have short life cycles, this will also limit their forecast lead time.

In recent years, nowcasting and VSRF rely more and more on “blending” techniques combining several data sources (both in situ and remote sensing observation, NWP, model output statistic (MOS) data, high resolution topography, heuristic rules) in a seamless way using lead-time-dependent weights. (see INCA[1]).

[1] INCA Integrated **Nowcasting** through Comprehensive Analysis; Wea. Forecasting, 26, 166–183. doi: 10.1175/2010WAF2222451.1

Variables like precipitation and wind near the surface can show large gradients even at small scale. For this reason in situ measurements could miss some local relevant features. Only remote sensing system can give an adequately wide coverage. Nowcasting in the early days developed therefore with the radar.

To be used in NWC, observational data must be transmitted and processed very quickly. Unfortunately many ground station data do not arrive in due time to the forecasters and NWC algorithms. On the other hand, the forecasts must be delivered to the interested end users accordingly.

While nowcasting can be done over any region, it is more frequently practised over populated areas or areas having important sensitive infrastructures, like cities, airports, power plants, railways, roads, electric grid, recreation areas or for special events and large venues such open air concerts or sporting events. NWC could also be needed for special missions like interventions in wild fires, floods, polluted or contaminated areas, or for regions where emergency forces have to act.

Nowcasting and VSRF were first practiced and developed due to the needs of the aeronautical community. For this reason many requirements of aeronautical meteorology include and expand upon those of nowcasting and VSRF (see SoG for Aeronautical Meteorology on the WMO website[2]).

An important step to bridge the data gaps in aeronautical meteorology is to use of observations from "hybrid systems" combining different data sources.

Sophisticated nowcasting techniques are now routinely used in developed countries where radar systems are mature and robust. However, in less developed countries the required operational radar systems needed for nowcasting are still missing. There are efforts to encourage developed countries to extend and adapt their existing nowcasting systems mainly to developing countries, where observational data is generally very sparse and also less frequently received (e.g. satellite data). Developing countries should be encouraged to develop "low cost" nowcasting systems based on satellite data and NWP since radar data is often non-existent.

Nowcasting and VSRF techniques can be applied to many phenomena. They are most frequently used to forecast: (1) convective storms with attendant phenomena; (2) mesoscale features associated with extra-tropical and tropical storms; (3) fog and low clouds; (4) locally forced precipitation events; (5) sand and dust storms; (6) wintertime weather (snow, ice, glazed frost, blizzards, avalanches), (7) wild fires and (8) contaminated areas. While there is some commonality with synoptic meteorology in forecasting these phenomena, nowcasting focuses greater attention on short time scales and fine spatial resolution covering small geographic areas. In recent years, there is a clear tendency to develop the nowcasting of "severe" weather. This also requires a special operational routine for the issue and delivery of warnings. These warnings are based on specific regional needs but also follow specific national or administrative regulations and thresholds. Nowcasting and VSRF observational requirements are best satisfied by frequent monitoring of the location, intensity, movement and evolution of the phenomena of interest.

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2 www.wmo.int/pages/prog/www/OSY/SOG/SoG-Aero.doc

In the past, a separate SoG for synoptic meteorology was available. Because the requirements for NWC and VSRF were considered similar to those for synoptic meteorology, with the former more strict where they differ, both SoGs were merged into one. In general, requirements for synoptic meteorology requirements are usually more homogenous in space, whereas for NWC the needs for resolution, observing cycle and timeliness can increase substantially near sensitive and/or populated areas particularly for surface or PBL variables.

Short-range forecasting (known as synoptic forecasting) could be defined as the activity performed by a forecaster when predicting the weather at time scales from 12 hours to several days, and at related space scales. Numerical Weather Prediction (NWP) output (global, regional and ensembles) play a vital role in synoptic forecasting combined with conceptual models. Many uses of the observations in synoptic forecasting and meteorology are thus related to numerical models:

- to be assimilated particularly by high resolution NWP with rapid update cycle;
- to evaluate the value of model output by comparing the analysis and early frames of a forecast (regarding timing, location and intensity of synoptic-scale features);
- to take appropriate mitigating action if a mismatch exists between model output and observations;
- to capture smaller-scale details that are unresolved by the models; and,
- to verify forecasts a posteriori.

This Statement of Guidance concentrates on uses other than via data assimilation and NWP, which are already covered in the SoGs for global NWP and high-resolution NWP.

Contrary to a NWP data assimilation system, where the goal is to estimate each atmospheric variable on a more or less regular grid, synoptic meteorologists attempt to depict meteorological phenomena more in an object-oriented way for selected phenomena (i.e. tornado). Forecasting methods evolve from looking at individual observing systems separately to integrating different data sources to infer meteorological variables and phenomena, so that the impact of the different observing systems discussed in this SoG is both by *objects* and by *data source*. In the regions where a sufficient station network is available, adequate interpolation techniques allow a gridding of the variables either with the observed values or with station MOS data. For NWC gridding, a fast data transmission is necessary.

Nowcasting is usually carried out in regional or national forecast centres. Because of the high refresh cycle and the large data input of the nowcasting techniques, they are mostly run automatically and the products can or should therefore be delivered to the end users with no forecaster’s intervention.

The following sections provide an assessment, for the main variables of interest, of how well the observational requirements for nowcasting and VSRF are met by existing or planned observing systems.

Surface and near-surface wind

Over land, surface observations have spacings that vary a lot from region to region. Accuracy is generally good, but the representativeness of the measurement can be very limited because of the instrument position and/or of the variability of the wind field near the ground. Data from many local meso-networks often provide denser observation sets which are very useful in the case that the data is made widely available. The interpretation of local wind data is complicated in mountainous terrain, where local diurnal circulations are common (e.g., mountain-valley winds or drainage winds).

Many stations only provide mean wind speed and direction, but no wind gust information. In NWC, wind gust is relevant information especially for severe weather.

In the vicinity of airports, wind shear, turbulence and sudden changes in wind speed or direction (e.g. increase in crosswind including gusts) are very important for landing/departing aircraft and air traffic management (such as change of runways). Local observing meso-scale networks, Doppler lidars and terminal Doppler weather radars are providing good wind information at selected locations in the developed world. Boundary-layer wind profilers provide useful information on vertical shear but are limited in sampling the horizontal wind changes over the flight paths for alerting wind shear. Present information on the wind behaviour in real time can be provided with acceptable uncertainty based on small-scale model case studies on the aerodynamic behaviour of such constructions.

For wind farm energy production, wind forecasts should be available at 50-150 m above ground. This can be achieve with a combination of measurements, MOS algorithm and NWP downscaling.

Over land surface and near surface wind measurements can be locally good, but for many regions just acceptable or even marginal for nowcasting applications.

Over ocean, ships and buoys provide wind observations of acceptable/marginal frequency and accuracy. Scatterometer data from satellites provide highly valuable data for oceans and seas with poorer performance around islands and coastal areas but with, at best, acceptable resolution. Cloud-motion winds are rarely capable of providing data continuously in the planetary boundary layer over land. Because scatterometers are on-board polar satellites, temporal resolution is poor or marginal for NWC.

3D wind field (horizontal component)

There are five types of measurement techniques:

- Radiosounding: accurate but low temporal resolution;
- Wind profiler: accurate and good temporal resolution, but possible contamination, in populated areas.
- Weather radar winds: less accurate and only during precipitation or thick cloud (+ marginally when insects). No wind data in clear air.
- AMDARs: accurate, but at some locations (airports) and at some times (little during night time). Good coverage over USA and major flight routes, marginal elsewhere.

- Wind vectors derived from objects tracking like convective cells or clouds: precise but related to specific object.

The 3D wind field requirements are generally similar/equivalent to those for aviation meteorology or high resolution NWP.

A special request is an accurate wind field for extrapolating the movement of object like convective cells. Tracking vectors could sometimes be misleading, i.e. in presence of complex orography. For NWC the data are acceptable, but usually just for less than one hour for individual cells up to several hours in case of larger synoptic driven structures.

Radiosondes remain the reference observing system for determination of detailed vertical structure in the atmosphere. This is due to their excellent vertical resolution (provided full resolution data are being transmitted instead of standard / significant level data only) and also to the simultaneous presence of temperature, wind, moisture and pressure measurements (moisture with marginal accuracy, all other variables with good accuracy). Vertical stability analyses, seeking details which are not necessarily captured by the NWP models, are based mostly on the radiosondes. Moreover, radiosondes remain one of the key observing systems in NWP analyses; the model assessment made by the forecasters relies to a large extent on them. Thus, despite the poor temporal resolution and uneven geographical coverage, radiosondes are of primary importance in synoptic meteorology, but much less for nowcasting.

Wind profiles are available from radiosondes in specific locations over populated land areas and from aircraft (ascent/descent) profiles over limited areas (airports). The temporal resolution of wind profiles from radiosondes is marginal to acceptable. Except for a few radiosonde stations and infrequent single level aircraft reports, wind coverage in Polar Regions is essentially absent.

Single-level satellite winds are available over low and mid-latitudes and provide acceptable horizontal and temporal coverage, but vertical coverage is marginal. Satellite winds are of acceptable to marginal accuracy. High-resolution wind products support nowcasting by providing atmospheric dynamics information at a scale much finer than the synoptic scale. Of particular interest is the information associated with the derivative of this product, i.e., wind shear and wind convergence. The product can also be used for aviation support and as input to regional NWP models.

Doppler wind profilers have been deployed over limited areas like USA, Europe, and Japan and are in strong development in countries like China and the Republic of Korea. Tropospheric profilers provide high vertical resolution and accurate winds at sub-hourly intervals from 0.5 to 17 km. Boundary layer profilers produce winds with similar attributes at altitudes from 0.1 to 8 km, depending on the weather conditions. Accuracy, vertical resolution, cycle time and delay are good. The good temporal resolution of wind profilers and the generally adequate data quality is making them quite useful, even for nowcasting when the instruments are located near sensitive infrastructures like airport or power plants. However, their geographical coverage is expected to remain marginal to poor except in a few regions of the world. Moreover, the cost of technical maintenance and the difficulty to obtain the necessary frequency bands are limiting their operational implementation. Wind profiler data over oceanic, sparsely populated and polar regions is nearly absent. An expansion of boundary layer profilers in combination with AMDAR profiles and VAD weather radars wind profiles may provide a means of improving upper air coverage over selected land areas.

Volumetric vertical profiles of winds up to 10 km of the ground are provided by Velocity Azimuth Displays (VAD) generated from scanning Doppler radars when sufficient atmospheric reflectors are available – normally, with precipitating systems or thick cloud, but also in clear air on dust and insects. In clear air, the VAD data can be contaminated by birds, so this information requires careful treatment.

Data available from either isolated radars or radar networks have good time resolution, of the order of a few minutes, but they are available only over populated areas. Overall horizontal and vertical coverage is generally acceptable and the vertical resolution is good, but it is confined to a small region around the radar (up to 50 km). Important information about the storm scale winds or local wind maxima, are provided by the Radial Doppler Velocity field, or by the Storm Relative Velocity field. These data are critical in determining the internal structure of the severe storms, and in the manner in which a storm can modify the environmental winds.

Near or just below the tropopause, single level aircraft winds are often available along primary air routes over certain areas in the temperate and tropical zones. At major airports, especially in populated areas, AMDAR data are providing an increasing number of high quality soundings.

Single-level satellite winds are available over low and mid-latitudes and provide acceptable horizontal and temporal coverage, but vertical coverage is marginal. Satellite winds are of acceptable to marginal accuracy. They can provide useful information in the development and evolution even on meso-scale systems.

The increasing availability of display software for AMDAR data, particularly for ascent/descent profiles is making these data a highly useful tool for forecasters, particularly in data sparse regions of developing countries when the number of AMDAR equipped aircraft will increase. Data quality is generally good, and quality control measures are being put in place to ensure adequate data integrity.

An expansion of the use of AMDAR technology over the next few years provides the best opportunity for increasing wind observations. While AMDAR vertical profiles of wind and temperature are limited to airports having suitably equipped aircraft, additional single-level data are given by AMDAR aircraft when flying at cruise altitudes. In addition to ingesting AMDAR data into NWP models, it is also important that the profile data be routed to local forecast offices for display on thermodynamic diagrams and on plan views of the atmosphere.

Precipitation

Precipitation is measured with adequate accuracy by automated and manual rain gauges, except for frozen precipitation or small scale convection. Network density is very variable and many stations are measuring only daily values or without real time transmission (i.e. hydrological networks, private owned/operated stations, etc.). The resolution in time and space can therefore be marginal or acceptable for nowcasting application.

Weather radars are essential for the detection of precipitation in real-time at high-spatial resolution. In areas where radar networks are installed, the horizontal and temporal resolution are excellent, and the accuracy of the quantitative estimation of precipitation is acceptable to good except for complex topography and/or light snow, where obscuration of low-lying areas hidden by higher topography is a limiting factor. Advanced volume scanning radars can estimate accumulated precipitation within acceptable to good accuracy and this can be substantially improved through real-time calibration with rain-gauge networks.

Radar polarimetry helps a) to distinguish better between weather and non-weather targets, b) to classify weather targets into different hydrometeor classes, c) to improve quantitative precipitation estimation and, if done properly, d) to improve the overall quality and robustness of the system. But, the quality of polarimetric information depends on how the system is designed and maintained, on several external factors such as water on the radome, and decreases rapidly with increasing range. Furthermore, most of the value added by polarimetry comes from the relation between drop shape and drop size, which is obviously only effective for the liquid phase. It is advisable to design the algorithms in an intelligent way such that one can exploit the added value from polarimetry where polarimetry works and relaxes back to single-polarisation algorithms where polarimetry fails.

Supplemental reports of accumulated precipitation are often provided on an event-driven basis by large numbers of non-professional cooperative observers reporting to nearby meteorological offices. This near real-time reporting can fill horizontal resolution gaps and be helpful in flash-flood forecasting, but only by fast delivery of the data.

Satellite based estimation of precipitation is the only valuable alternative in absence of radar and very sparse real time rain gauge data. Estimation techniques usually work better for convective precipitation, typically in tropical regions. Lightning data could complement the satellite information in this case.

Meteorological satellite data are well suited to monitoring in a qualitative way the initiation and rapid development of precipitation generating systems both in space and time. Rapid imaging (on the order of minutes) is critical to nowcasting, but it is not yet provided by all geostationary satellites. With some satellite systems, the rapid scan of small areas competes with broader coverage requirements. Frequent images from geostationary satellites provide good to adequate horizontal resolution for identifying the initiation, evolution and movement of synoptic and mesoscale cloud systems or of local circulations over most of the tropics and temperate zones.

The more frequent and more comprehensive data collected by latest satellites will also aid the weather forecasters in the fast recognition and accurate prediction of dangerous weather phenomena such as thunderstorms, thus forming an important contribution to nowcasting.

Using the polar orbiting satellites, the combined analysis of two different types of observations (high-resolution multi-spectral imagery and microwave observations) allows for a higher quality of the precipitating cloud product. The combination of polar and geostationary satellite information can improve the precipitation estimate giving a better coverage and resolution both in time and space. Such techniques are available only in limited regions at present time.

The detection of precipitation is marginal for microwave imagers and depending on the wavelength of the instrument good to poor for scatterometers. Precipitation estimates derived from satellite measurements are improving. Microwave radiometers, and precipitation radars have marginal capability of estimating precipitation for Nowcasting. The nature of the phenomenon (short-lived convective cells and rain bands) limits the use of data for quantitative assessments of accumulated precipitation.

There are products for rainfall rate estimated specifically from convective clouds. They are complementary nowcasting products which provide information on the characteristics of precipitating clouds and cloud type.

Surface pressure

Surface pressure is a standard measurement on synoptic stations and at airports for reporting QNH/QFE and is usually measured today by automatic digital barometers and on site, providing more reliable measurements. Surface pressure is fundamental for synoptic analysis and is used in dedicated algorithm like wind gust nowcasting estimation. Horizontal resolution is good over populated area and marginal over ocean and deserts. Time resolution for NWC is good on some networks and acceptable for airport station.

No useful surface pressure information for nowcasting and VSRF is available from satellite.

Surface air temperature and humidity

Surface air temperature and humidity measurements are standard on aviation and synoptic stations both manned and automatic. Over land, surface stations measure with horizontal and temporal resolutions which are good in some populated areas and marginal in others such deserts. Measurement accuracy is generally good. On the other side the timeliness of the data transmission is very variable; for NWC applications it ranges from marginal to good.

Over ocean, ships and buoys provide observations of acceptable frequency and accuracy (except ship temperatures during the daytime, which currently have poor accuracy). Coverage is marginal or absent over large areas of the Earth. Over land, surface stations measure with horizontal and temporal resolution which is good in some areas and marginal in others. Most of the stations are on flat land or on valley bottom. This drawback can be partially overcome with good interpolation techniques considering the topography. This can be used to estimate the snowfall line in case of precipitation over complex terrain.

Satellite instruments do not observe these variables, or do so only to the extent that they are correlated with geophysical variables that significantly affect the measured radiation (i.e. skin temperature and atmospheric layer-mean temperature and humidity).

3D temperature field

The 3D temperature field requirements in NWC/VSRF are generally similar/equivalent to those for aviation meteorology or high resolution NWP.

For the high resolution analysis and forecast of the snowfall level and the air pollution evolution high resolution NWP field have to be "adjusted" with observation data (blending techniques).

In nowcasting, the temperature and humidity fields are particularly useful for determining atmospheric stability for predicting convective storms initiation, precipitation type, the possibility of hail and the amount of frozen precipitation. The vertical profiles of temperature, moisture and winds provide the basic information for convective nowcasting.

Current systems, with the exception of radiosondes and AMDAR, do not have the vertical resolution required to resolve the PBL top, and so their capability is poor for such applications as forecasting the initiation of convection (i.e. geostationary satellites or ground based radiometers).

3D humidity field

The 3D humidity field requirements in NWC/VSRF are generally similar/equivalent to those for aviation meteorology or high resolution NWP.
Humidity field retrieval from remote sensing system has a poor vertical resolution for NWC (geostationary satellites, ground based radiometers, GPS).

The retrieval of humidity fields from Doppler weather radar using ground clutter targets is an innovative development in recent years, but there are just a few examples of operational use of this information, otherwise it is at best experimental. It provides acceptable temporal and horizontal resolution but coverage is marginal since it relies on ground clutter targets (available only near the radar).

Cloud amount

At synoptic and airport stations cloud type, amount and base are standard. This observation are mostly done manually and cannot easily be automated. For this reason the availability and in some case even the quality is generally decreasing due to the difficulty to have qualified observers. The horizontal resolution is at best acceptable or marginal. For NWC only aviation reports have a good or acceptable resolution because often restricted to the airport operation time.

The steadily improving horizontal and spectral resolution of geostationary satellite instruments leads to improved detection and classification of clouds. Progress has been made on night-time detection of low clouds, which used to be marginal, and on distinction between high-thin and high-thick clouds (e.g., cirrus versus cumulonimbus).

Geostationary satellites imagery is the prime source for locating synoptic-scale features and objects in real-time, allowing them to detect any incipient discrepancies between NWP products and reality at an early stage. This is particularly true over oceanic areas, where conventional data are typically very sparse. NWP fields and satellite imagery may be superposed on a workstation screen; a good example is given by the potential vorticity field of the upper-level flow correlated with water vapour satellite images. The horizontal resolution and coverage are good, except over the high latitude regions (60-90N and 60-90S). With the new generation of geostationary satellites and by moving from imaging channels to sounding channels, the errors in cloud height assignment should be reduced, but the vertical resolution will not improve significantly, because still limited to seeing the cloud-top of the uppermost layer.

Meteorological satellite data are well suited to monitoring in a qualitative way the initiation and rapid development of precipitation generating systems both in space and time. Rapid imaging (on the order of minutes) is critical to nowcasting, but it is not yet provided by all geostationary satellites. With some satellite systems, the rapid scan of small areas competes with broader coverage requirements. Frequent images from geostationary satellites provide good to adequate horizontal resolution for identifying the initiation, evolution and movement of synoptic and mesoscale cloud systems or of local circulations over most of the tropics and temperate zones.

The more frequent and more comprehensive data collected by latest satellites will also aid the weather forecasters in the fast recognition and accurate prediction of dangerous weather phenomena such as thunderstorms, thus forming an important contribution to nowcasting.

An operational satellite-based retrieval of these derived variables provides good potential for the identification of pre-convective conditions.

Polar orbiting satellite infrared and visible images continue to deliver excellent horizontal and spectral resolution, with their use being limited only by the infrequent availability of the data. However, for the high latitudes, where geostationary satellite data are missing, the polar orbiting satellites provide valuable observations with acceptable frequency due to the convergence of orbital tracks.

Visibility, cloud and base height

Aviation and synoptic surface observing stations, both automatic and manual, measure visibility an cloud base height at many locations where nowcasting and VSRF is practiced. The sites are often at or near airports and population centres and provide a comprehensive description of meteorological variables. For most variables, the accuracy of the data is adequate to good. Over land, data from an increasing number of automated stations contains weather elements such as cloud cover or visibility. Over the oceans these variables are usually not observed. Near the airports 1-D or 3-D very high resolutions models can estimate visibility and cloud base forecast in the NWC and VSRF range with useful accuracy. These models need several high frequency observing additional stations. For this reason they are available only in very few airports.

Satellites do not observe horizontal visibility, but some blending techniques allow an interpolation of station observation with cloud estimates from satellites.

Visibility and cloud observation are generally good at the airports, but marginal elsewhere. For road safety and management visibility NWC will be useful, but adequate data are generally missing.

A special case of visibility reduction is the presence of volcanic ash (particularly relevant for aviation routing) and heavy dust or sand storm. Solid particles can be detected by satellites in cloud free areas with appropriate algorithms, but usually without discrimination between sand/dust and ashes. For volcanic ash, time and horizontal resolution are quite good, but poor in the vertical. LIDAR provides good vertical profiles, but very few instruments are operational worldwide.

Lightning detection

Ground-based (total or separately cloud-to–ground (CG) and intra-cloud (IC)) real-time lightning detection have demonstrated their value as an early indicator of the location and intensity of developing convection, and also of the movement of thunderstorms by tracking methods. By identifying electrically active storms in space and time, these systems increase warning lead times for dangerous thunderstorms which may have major impacts on aviation, the electric power grid, mobile phones companies, satellite transmissions, oil and gas companies, forest management, fires control, marine and recreational activities.

Often single detected flashes are aggregated/accumulated either by the provider before to be broadcast or by the users in order to be displayed or combined with other data.

For meteorological applications no single flash information is necessary, but a good resolution in space and time of the lightning density, i.e. the number of detected flashes in the corresponding time interval and the space unit. These data can be easily combined with other remote sensing data (i.e. radar) in order to characterize the convection.

There are different technologies ranging from low to high detection frequency (from 300 kHz up to 30 MHz) and the corresponding network density, resulting a variable detection efficiency. The horizontal resolution of these systems is good (within a dense network) to average depending on the distance to the receiving antennas. Single lightning can be characterized by several attributes in addition to the position and time (i.e. discrimination of CG from IC, positive and negative discharges can be relevant for meteorological applications). Most networks cannot discriminate CG from IC and/or have a poor detection efficiency of intra-cloud lightning. Research has shown the importance of these data for the early detection and phase evolution of convection.

Over most oceanic, sparsely inhabited land and high latitudes, coverage is marginal to acceptable by ground-based networks. Cycle time and delay are usually good. In some countries efforts are under way to expand lightning detection systems to cover more oceanic nearby areas. Advanced lightning systems also provide the 3-D structure of the electrical activity. As exploited by NSSL (Oklahoma Lightning Mapping Array), under such technique, up to thousands of points can be mapped for an individual lightning flash, to reveal its location and the development of its structure. Scientists hope to learn more about how storms produce intra-cloud and cloud-to-ground flashes and how each type is related to tornadoes and other severe weather. Better lightning mapping techniques show that some supercell thunderstorms have "lightning holes" where updrafts are located and precipitation is scarce. If these holes form, as suspected, just before a storm becomes severe, this information could alert forecasters to developing severe conditions. This has particular special value for aeronautical purposes.

Lightning imager instruments are on some LEO satellite (TRMM) and are planned for next generation GEOs (MTG, GOES-R, FY, Electro-M). These detectors measure in the near infrared (777 nm), but cannot discriminate IC from CG. Comparisons between satellite and ground based lightning detection can show large discrepancies probably because of the large frequency range differences of the instruments. The temporal resolution is currently marginal, but should significantly improve with the new GEO missions. Horizontal resolution and accuracy are lower than most ground-based detection, particularly near the antennas.

The strength of the lighting information is provided by the almost real-time sampling of the atmosphere, and provides added value to radar and satellite data. The ‘satellite-radar-lightning’ trio is the basic building block for a good nowcasting observation system for convection.

Downward short-wave irradiance at Earth surface

Many automated stations measure solar radiation as well. This variable can be used as input to forecast the energy needs for heating and cooling of buildings and to estimate the energy output from solar power plants. Usually horizontal resolution is marginal, but when combined with satellite cloud coverage information acceptable quality can be achieved.

Sea surface temperature

Same requirements as SoG High-Resolution NWP (see website[3]).

Sea-ice

Same requirements as SoG High-Resolution NWP (see website[4]).

Snow

Over land, surface stations measure snow cover with good temporal resolution where automated, much less when manual, but marginal horizontal resolution and accuracy (primarily because of spatial sampling problems), particularly over complex terrain where large small scale gradients are observed.

Visible / near infrared satellite imagery provides information of acceptable horizontal and temporal resolution and accuracy on snow cover (but not on its equivalent water content) in the day-time in cloud-free areas. Microwave imagery offers the

[3] http://www.wmo.int/pages/prog/www/OSY/SOG/SoG-HighRes-NWP.doc
[4] http://www.wmo.int/pages/prog/www/OSY/SOG/SoG-HighRes-NWP.doc

potential of more information on snow water content (at lower but still good resolution) but data interpretation is difficult. Data on snow equivalent water content are relevant to estimate the river runoff of snow melting caused by rain, when they are coupled to hydrological models.

Snow cover over sea-ice also presents data interpretation problems.

For NWC high resolution snow observations are very important for road and railway maintenance and operation, snow load estimation for electrical grid. Usually the horizontal resolution is at best acceptable, but with good precipitation, temperature and humidity data the snow amount can be estimated.

Soil moisture

The information on soil moisture used in NWC comes usually from the same observing systems as the ones used in high resolution NWP (see SoG for HiRe NWP).

The very sparse soil moisture measurement stations could increase because of their interest: together with snow depth, vegetation and other variables, soil moisture is very important for processes describing the surface fluxes and the atmospheric boundary layer. This information is also needed to compute the forest fire risk indices.

Measurement accuracy of scatterometers (ASCAT) as well as temporal resolution are acceptable, while the horizontal resolutions still is, at best, marginal.

Lake-sea-ice surface skin temperature

The same observations are used and the same statements apply as the ones of high resolution NWP. The same difficulties of interpretation and representativeness exist, but they are continuously reduced with the reduction of model mesh sizes which become more and more representative of the horizontal scale of the observations.

A very important orographic gradient is the land to water transition, where important small scale effects are possible (i.e. thermal winds). Good data are also valuable to produce high resolution forecasts. The actual space resolution is nevertheless marginal to acceptable.

Wave height, direction and period

Ships and buoys provide observations of acceptable frequency and acceptable/marginal accuracy. Coverage is marginal or absent over large areas of the Earth.

Altimeters on polar satellites provide information on significant wave height with global coverage and good accuracy. However, horizontal and temporal coverage is marginal. Information on the 2D wave spectrum is provided by SAR instruments with good accuracy but marginal horizontal and temporal resolution.

Additional comments on satellite observations

For NWC applications several products are derived from geostationary satellite data combined with NWP model ones. Their time and horizontal resolution are usually acceptable. Beside cloud properties (see above), there are other variables for clear air/cloud free areas.

Air mass variables (like precipitable water and a few stability indices) derived from satellite data can also be used to issue severe weather warnings, if a derived severe weather index exceeds a certain threshold. These thresholds are generally determined empirically and should not be regarded as fixed values. A skilled local forecaster is usually necessary for a correct interpretation. An operational satellite-based retrieval of these derived variables provides good potential for the identification of pre-convective conditions, but they are only available in cloud-free areas.

The Rapidly Developing Thunderstorms product monitors thunderstorms from MSG data. It automatically identifies, monitors and tracks intense convective systems so detects of the existence of rapidly developing convective cells. These highlight the most active cells, and can be therefore be used for the automated convection detection.

Automatic Satellite Image Interpretation is an automatic diagnosis of typical cloud structures based on conceptual models. It identifies complex meteorological phenomena like fronts, wave structures, areas of intensification at fronts, positions of the jet stream axis, comma clouds and enhanced convection areas, etc.

While coverage is good over mid-latitudes and tropical areas, coverage over high latitudes is marginal or absent.

Polar satellite microwave imagers and sounders offer information on liquid water and precipitation with good horizontal resolution but marginal temporal resolution. It has acceptable accuracy (though validation is difficult) only if other precipitation data (radar or rain gauge) are missing.

Additional comments on weather radars.

Conventional scanning weather radars can detect and track the movement and intensity of convective and non-convective systems over many populated areas where nowcasting techniques are primarily practiced. Radar data are valuable in precise quantitative measurements, identifying heavy rain, severe hail, high straight-line winds and tornadoes (if Doppler capability is available) in single cellular convective storms as well as in more organized convection, like linear or clustered multi-cellular storms, associated with extra-tropical and tropical storms. The use of weather radars precipitation cells trajectories is also a tool commonly used for nowcasting. The location and intensity of locally forced precipitation events such as those found downwind of large water bodies, or with upslope enhancement, can be monitored.

Clear air detection by radars can help identify the regions where lifting mechanisms develop giving a good precursor to convection initiation. Coverage over many populated areas is marginal to acceptable, but over oceanic and sparsely inhabited land areas coverage is marginal or absent since it is a low level phenomena. Where available, the time resolution of radar scans is about 5 -10 minutes at regional level. The coverage, in well-sited radars where orography does not block the beam, is circular regions of several hundred kilometres in diameter. Due to the strong societal impact of severe weather in recent years, there is a general increase in the interest of many nations to develop radar networks, and even to join existing networks. These large cross-border composite radar networks provide information at a lower resolution than the local radar data, but are of great value for regional monitoring.

The special case of tropical cyclones

Geostationary satellites provide vital information on the location of a tropical cyclone with a good temporal resolution and a good horizontal coverage; the availability of such information all over the tropical belt is essential. Polar orbiting satellites provide more detailed information on tropical cyclones, but at a coarser temporal resolution. For the surface, wind scatterometers are most useful. They also provide some capability for detecting precipitation.

Ground-based precipitation radars have a good horizontal and temporal coverage around land (including islands) areas, but are absent over most oceanic regions. They allow good monitoring of tropical cyclones and landfall, and they contribute quite significantly to nowcasting and very short range forecast, but not to their longer-term forecast.

Conventional *in situ* data provide marginal coverage over tropical cyclones, but measure MSLP with a good accuracy (one of the essential variables of a tropical cyclone); they also provide measurements of wind with good accuracy.

Targeted observations like dropsondes have been used for tropical cyclones, and have proved to be very useful not only for NWP usage but also for direct use by forecasters.

SUMMARY OF STATEMENT OF GUIDANCE FOR NOWCASTING, VERY SHORT RANGE AND SHORT RANGE FORECASTING

Nowcasting and VSRF users are a very inhomogeneous community with a wide range of requirements. Nevertheless we can identify following key variables for which observational data are required:

- clouds and precipitation;
- 3-D wind field;
- 3-D humidity field;
- 3-D temperature field;
- surface variables: pressure, wind (including wind gust), temperature, humidity, present weather, visibility and precipitation intensity/accumulation, short wave irradiance, snow layer, soil moisture, lightning, fires;
- dust/sand/volcanic ash;

The horizontal resolution of observations of most surface variables and phenomena needed for nowcasting and VSRF is acceptable in some populated area but marginal to absent in sparsely populated areas and above seas. Only a subset of all available surface observations arrive in useful time to the weather centres, particularly for nowcasting applications. Interpolation techniques can provide real time high resolution fields for many surface variables, but the measurement frequency should be increased (i.e. automated), the data transmission accelerated and where possible some automatic QC introduced. Many automatic stations belong to external networks of the NMS and the data are not integrated; for that reason many valuable information do not reach the data centres (at least in due time) and cannot be integrated in the forecast processes.

Wind field and wind shear data do not yet have the needed resolution for aeronautical meteorology in all places but use of composite systems could overcome this gap. Good coverage is required in weather sensitive areas, such as airports, harbours and cities. Many stations only report mean wind speed and not the wind gust values. This latter value is necessary for several nowcasting needs.

Scanning weather radar coverage (especially Doppler) is good in developed countries and near critical places, but much less elsewhere. They provide excellent information critical to improving nowcasting and VSRF of convective and stratiform precipitation with their potential for localised flash floods, tornadoes, hail and high winds.

Lightning detection systems, for cloud-to-cloud and/or cloud-to-ground lighting, are important for convective electrical activity monitoring and bring valuable information about storms structure and evolution.

Cross-border radar and lightning data exchange is difficult for some countries that do not have a memorandum of understanding or protocols for these exchanges.

Radar data and lightning data belonging to other bodies than meteorological services (private companies, agencies, utilities, TV networks, etc) are missing from the national or regional public integrated products. Developing parallel exclusive networks for electrical activity and radar monitoring is not an efficient way to use national resources; these networks should be integrated for better monitoring of severe weather.

For frequently updated fields of 3-D wind and temperature important for nowcasting and VSRF, the increasing number of AMDAR observations provides high resolution wind and temperature data at the tropopause level and composites of radio-soundings, wind profilers, weather radars VAD and AMDARS provide tropospheric wind observation over populated regions. AMDAR coverage is dense over the USA, Europe, eastern Asia, North Atlantic and major flights routes, but sparse elsewhere.

Doppler wind profilers have proven valuable because they provide high vertical and temporal resolution as a complement to other upper-air observing systems, but the horizontal resolution is at best acceptable.

Well-defined high spatial and temporal resolution multi-spectral imagery from space is providing important immediate benefits to nowcasting phenomena such as areas of cloud, fog, dust, fires and severe convective weather. Several products are derived from the original satellite channels for specific NWC application, but not available for all satellite (like EUMETSAT NWC SAF[5], or HydroNowcaster[6]).

Rapid imaging (on the order of minutes) is critical for nowcasting, and is increasingly but not yet fully available for all geostationary satellites. With some systems, the rapid scan for small areas competes with the scanning requirements for broad coverage.

Some of the derived satellite estimates relevant for severe weather monitoring (like air mass instability) are not yet tuned for specific regions and thus have only qualitative value.

For the high latitudes, where geostationary satellite data are missing, the polar orbiting satellites provide valuable observations with acceptable frequency due to the convergence of orbital tracks.

The temporal resolution of satellite microwave imagers needed for liquid water and precipitation is marginal. The accuracy of these data can be validated only over populated areas where radar data and rain gauges are available. Wind data coverage in high latitudes is poorer because of the difficulty for deriving of AMV in these areas, but should improve with the new generation of polar satellites.

Reliable and accurate precipitation estimates from satellite can represent an acceptable alternative over unpopulated regions without radars.

NWP models are the most important tool for short-range prediction, leading to a strong dependence on the same data as identified as sources for NWP. Thus, the SOG for global and regional NWP applies for NWC/VSRF as well. Information that best complements these data is found in satellite imagery and weather radar data; their usage is further supported by their good temporal and spatial resolution. Nowcasting is more needed/relevant where people live or vulnerable infrastructure is present. Usually

5 http://www.nwcsaf.org/HD/MainNS.jsp
6 http://www.star.nesdis.noaa.gov/smcd/emb/ff/HydroNowcaster.php

in these areas more surface observational data are also available, but much less in developing countries. Another concern is the quality of cloud cover and base height estimates in remote areas, and especially during the night, but some progress is expected in this area from new satellite sensors over the next decade.

Over land surface, data from an increasing number of automated stations contains, as a minimum, information on wind, temperature, moisture and mean sea-level pressure, with weather elements such as cloud cover or visibility mostly available from manned and aeronautical stations. Regional efforts are underway to collect, standardize, and quality control data from observing networks from non-NMHS sources such as hydrological services, road networks and private and industrial operators.

Non-professional cooperative observers of high impact meteorological events (like measurements of rain accumulation in flash floods cases, or spotters of tornadoes, strong winds, or large hail fall) exist only in some developed countries.

Snow depth data and fresh snow layer spatial and temporal resolution are not sufficient for urban areas and along major highways route. Snow profile of the snow-pack is done only in few mountain stations. This can be computed with fair results with good precipitation, 3D temperature and humidity fields.

Over the oceans, fewer variables are available. Mean sea-level pressure, measured on ships, buoys, and islands is a key tracer of synoptic activity. Even very isolated stations may play an important role in synoptic forecasting, especially when they point out differences with NWP model output.

Observational data (both surface and remote sensing) must be transmitted fast and with high frequency otherwise cannot be used for nowcasting and VSRF.

Many available satellite products do not reach their potential users because of: poor or missing reception facilities, problems with adapting the configuration of existing receiving and display systems, or insufficient training.

Actions to fill the gaps

1. Technical and infrastructure

- Increase the radar density networks, improve the frequency and geometry of the scanning observations and the volume coverage pattern chosen. Enhance the capacities for telecommunications and computing. To improve the precipitation estimation by radar some calibration with rain gauge observation are beneficial. More radars should be installed mainly in the sensitive areas (airports, harbours and cities).
- Avoid the spread of national resources in development of parallel exclusive radar and lightning networks instead of integration and enhance of the current ones.
- Improve the real time access to satellite data and derived products (i.e. EUMETSAT SAFNWC).
- Foster the development and use of merging and interpolation techniques

for estimated/measured data from different data sources in order to produce high resolution fields for relevant variables in real time (“hybrid systems”).

- Foster the blending techniques between observation and NWP to produce seamless forecast over all ranges (NWC-VSRF up to medium range).

2. Data quality and availability

- Improve the use of QC/QA techniques and recording of metadata (with reference to the WMO WIGOS and RRR tables: www.wmo-sat.info/oscar/)
- Recommend “opening” of data if the data belong to private companies, at least in case of “significant events”.
- Make a larger use of specific observation networks data (all power plants, electrical grid operators, mining industries, pipeline operators, TV stations, pollution, military, forest, etc.).
- Obtain rapid transmission of all real time observations both from surface stations and from remote sensing systems.
- Develop non-professional alternative observations networks like trained spotters network, meteorological observations performed in schools, cell phones, web cameras, etc.
- Support the cross-border exchange of radar and lightning data and meteorological observation stations data in the vicinity of the borders.
- Archive high resolution radar data for climatological studies of severe weather based on “radar objects” (i.e. climatology of supercells).
- Achieve faster delivery of the forecast products to users/customers.
- Increase the forecaster training on state of the art forecast methods and use of all available data/products.

3. Capacity Building for Cross Border Severe Weather Management

For public benefit and for developing countries:

- o Install low-cost nowcasting systems (based on satellite and NWP in regions with lack or radar data); organize regional virtual centres of guidance in observation and forecasting severe weather and provide free access of developing countries to severe weather products displayed on Internet.

- o Urge Member States to adopt Memorandum of Understanding and Protocols on regional radar data observational data exchange (particularly regional radar data), and organize enhanced and rapid exchange of data during severe weather events.