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(IPET-OSDE)
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ROLLING REVIEW OF REQUIREMENTS AND STATEMENTS OF GUIDANCE

STATEMENTS OF GUIDANCE

CLIMATE (OTHER ASPECTS – CCL)

(Submitted by the Secretariat)

SUMMARY AND PURPOSE OF DOCUMENT

The document provides information on the current status of the Statement of Guidance for Climate Applications (other aspects – CCI).

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.

Appendix: A. Statement of Guidance for Climate (other aspects – CCI)

DISCUSSION

1. Status of Statement of Guidance

For the present the WMO Commission for Climatology (CCI) considers that GCOS Essential Climate Variable (ECV) specifications constitute a good basis for addressing quantitative gap analysis and observation requirements. However the new and evolving requirements for climate services under the Global Framework for Climate Services (GFCS) go beyond this understanding of observations requirements, which are mainly pertinent to climate monitoring.

CCI would emphasise that other requirements and specifications that ensure good observational practices and related data management aspects - which by their nature are often non-quantitative - have been essential for CCI in its current intersession period (2010-2014). CCI perspective in this area was highlighted in its contribution to the Statement of Guidance (SoG) for Climate Applications (other aspects, CCI) in 2012. From a Climate Applications viewpoint it is important these requirements are captured and understood, to ensure that observations collected are also well quality controlled, homogenized and made available with the required timeliness and completeness for use in providing useful products and services.

2. CCI mechanism for reviewing and updating the SoG

CCI will decide on a new structure at its sixteenth session, Heidelberg, Germany 3-8 July 2014. As part of its Panel on climate data management (OPACE-1), CCI will decide on establishing a Task Team on Statement of Guidance which should address the gap analysis aspects. This will include reviewing the applicability of the GCOS specifications for observations to broader climate services, and developing requirements for non-ECV variables such as phenomena and evaporation.

Furthermore CCI will decide on the potential for setting up an Expert Team on Volunteered Observing Networks to guide Members on the minimum observational and metadata requirements and best practices for these networks. This will contribute to the provision of an updated SoG on observational requirements for local climate services.

APPENDIX A

STATEMENT OF GUIDANCE FOR CLIMATE (OTHER ASPECTS – CCL)

An analysis of current and emerging capacity gaps in surface and upper air observations to support climate activities.

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(Version updated in May 2012 by the PoC, and approved by the ET-EGOS-7, May 2012)

1. Introduction.

This document is a part of the *Statement of Guidance for Climate*, as requested by the Expert Team for Evolution of the Global Observing System (ET-EGOS). It outlines where CCI believes current observational practices and trends in observations fall short of climate program requirements; and/or where CCI believes observational programs should place particular emphasis. It should be noted that this is a first draft only, is largely qualitative, and will evolve. In particular, we plan to undertake a more comprehensive survey of climate service providers and their stakeholders in an attempt to better quantify some of the requirements. The emphasis here is mainly on *in situ* surface and upper air observations, though there are some references to remote sensing applications for climate purposes.

The document attempts to do two things. Firstly, it highlights the need for observations to support climate services *apart from* climate monitoring via the GCOS networks (which emphasise observations of the GCOS *Essential Climate Variables*¹ at selected high quality sites). A separate Statement of Guidance exists for these. The second purpose of the document is to emphasise the basic requirements for observational data that apply to both GCOS and non-GCOS variables and stations alike (e.g., the need for data backups, and ongoing collaboration between observers and climate staff). Adherence to the GCOS Climate Monitoring Principles (Annex 1) is mandatory for GCOS or other stations designated as “high quality monitoring stations”, but is strongly encouraged for other stations.

The document also includes discussion of broader issues such as network planning and observational change management, as these are crucial to the maintenance of a fit-for-purpose Climate Record. They are recommended practices for all NMHS in establishing and maintaining observing networks capable of meeting the needs of climate service providers, climate monitoring and climate research. There is also discussion of data management-related requirements such as data rescue and data flows which, while not entirely the province of observational programs, do involve them as stakeholders. It is important, for instance that the data flows from point of observation to the climate database do not lead to loss or corruption of data or metadata.

The GCOS Essential Climate Variables include air temperature, precipitation, atmospheric motion (i.e. winds), air pressure, humidity and solar radiation.

The non-GCOS Climate Variables include:

- Pan evaporation and sunshine (daily totals);
- Soil temperatures (at least daily minima and maxima) and terrestrial minimum temperature;

¹ The Essential **GCOS (?)** Climate Variables are air temperature, precipitation, atmospheric motion (i.e. winds), air pressure, humidity and solar radiation

- Visual observations (e.g., present and past weather type at standard synoptic observations times (at least 9am, or 9am and 3pm), cloud² – amount and type of different layers plus total amount, to nearest eighth), Visibility;
- phenomena (thunder and hail, lightning, dust, fog, frost), and daily incidence of phenomena;
- Daily wind run; and
- Soil moisture

Non-GCOS stations correspond to what the *Guide to Climatological Practices* terms “Ordinary Climatological Stations”, and precipitation-only stations. These stations have less stringent requirements for maintenance than for GCOS stations. CCI believes NMHSs should regard the GCOS standards for accuracy, frequency and reliability as aspirational for all climate and precipitation stations. However where it becomes a question of priorities, the GCOS and other high priority stations (“Principal Climatological Stations”) should be afforded the highest priority³.

As noted in the more general *Statement of Guidance* there is a need for a large number of other types of meteorological, hydrological, oceanographic, cryospheric and other environmental measurements. These are not dealt with specifically in this document, however the general principles for measuring these variables and managing the networks are as outlined in this document.

Major needs summarised

- To effectively support climate monitoring, climate service provision and climate research, climate science practitioners regard their major needs for *in situ* observations as: Longevity, sustainability and completeness of observations at stations (the latest *Guide to Climatological Practices* (2011) recommends at least 30 years of homogeneous records for rainfall to adequately describe the mean and variability, though the length can be shorter for other variables);
- Homogeneity and stability of measurement practices, such as instrumentation, siting etc;
- Adequate traceability, metadata and documentation around observational practices;
- Involvement of climate programs in network planning, and consultation where changes are planned which might impact on climate services; and
- Adherence to the GCOS Climate Monitoring Principles (Annex 1) – certainly for the *Essential Climate Variables*, but as far as possible at non-GCOS sites and with non-*Essential Climate Variables* such as visual observations and phenomena.

2. Requirements and Gaps

2.1 A need for early and ongoing consultation between climate and observations staff

Climate monitoring and climate services require, above all, long-term, continuous, homogeneous time-series. Therefore, when changes at stations or across networks which affect these requirements are likely or planned, consultation should be undertaken with climate programs, both in advance of the change, and periodically during planning and implementation. This applies to changes at a network level (distribution of stations, fundamental changes in functions, etc); changes at a station level (configuration of layout and set of instruments, instrument exposure, station management/inspections/maintenance, data acquisition, processing and communications, reporting frequency and format, etc); and changes at

² At the recent (October 2011) WCRP Open Science Conference in Denver, USA, presentations during the session on climate modelling indicated that parameterisation of low clouds was a major challenge. Yet observational programs in many NMHS are moving in the direction of fewer observations of cloud type, height and amount.

³ Some countries support networks of high quality stations that include the GCOS and Reference Basic Climate Network Stations, but are not confined to these. It should be noted that CCI believes the GCOS umbrella should be expanded to include at least each country’s RBCN stations, as these provide more information on climate niches, vulnerable areas, and socio-economically-important locations within a country.

a measurement level (sensors and instruments; manual and automated techniques including algorithms, whether the data are manually transcribed, etc). The implications of such changes will vary according to the significance of the station to climate services and monitoring.

- There is therefore a need for climate specialists to be involved at an early stage in, and regularly consulted about, planning involving implementation, cessation, or changes to observational (and IT) systems which may impact homogeneity or completeness of the Climate Record. Ideally, there should be a process for climate programs to sign off on the plans and implementation stating that they are satisfied there are no adverse impacts from their point of view.
- Equivalently, it is important that there be mechanisms for climate programs to accurately communicate to network operators new and emerging requirements for climate data. For example, the availability of high frequency data from AWS is generating an increasing demand for such data. This is because the implementation of new technologies and new solutions to meet the challenges involves long lead times, during which there should be an active dialogue between user and provider regarding measurement needs.
- Addition or removal of stations, or planning for changes in siting, should be accompanied by an impacts analysis. The impacts analysis could be qualitative (are specific climate services affected?), and/or quantitative (does the proposed change adversely affect climate mapping or areal analyses?) Either way, consultation with the NMHS climate program is required.

Ensure adequate change management processes

- NMHSs should be encouraged to ensure there is adequate change management when observational systems change, or before implementing new systems. Sound change management practices include:
 - Involvement of climate specialists in the planning and scoping of the changes;
 - Assessment of all elements of the measurement chain prior to installation or implementation in the field. Any change to algorithms; sensors make, model or method; electronic or environmental interfaces; manual procedures and training; sampling methodologies; siting etc needs to be evaluated. This evaluation may range from expert desktop assessment, literature (e.g. WMO intercomparison), through to laboratory testing, application of data tests and field trials.
 - Some form of formal “sign off” by climate programs following planning and implementation stating that they are satisfied there are no adverse impacts from their point of view.
- Parallel field trials are required when, for instance, automated stations replace manual ones, or there are other significant changes to observation technologies. Where changes to AWS are made, it is recommended that testing also include comparisons of the effects of different operating systems within the AWS to distinguish differences due to algorithm and sensor from software/communications effects.
- At the very least the climate program needs to be informed about pending changes, in a timely fashion where possible⁴. Adherence to such Guidelines could be facilitated by reminding Observational managers within NMHS of the importance of adhering to the GCOS Climate Monitoring Principle, and relevant parts of the *Guide to Climatological Practices* (especially Chapter 2).

2.2 Technical

Minimise missing data

⁴ Moreover, it is recommended that the advice be conveyed to a designated list of stakeholders, to minimise the risk that advice of a major change does not reach stakeholders who may be significantly impacted.

- For climate purposes, missing data should be minimised. Current guidance (ref needed) specifies that monthly means should have no more than five missing values, and no more than three in succession, although this requirement will be reviewed in due course and often reflects a trade-off between data density and fidelity. This has implications for the staffing and equipping of climate stations, noting also the following point.
- For climate purposes, a desired data availability rate of 99% has been specified, i.e. no more than 1% of observations should be missing or unrecoverable. To this end, all automated observing systems should have backup and retrieval facilities to maximise the chance of being able to recover the data in the event of a communications or systems failure. Minimum standards will be published in a forthcoming document summarising climate requirements from AWS, but at this stage the recommendation is likely to be that a minimum of three months of data at the shortest-available recovery period (hourly or one minute data) should be logged on-site, and 12 months for a GCOS site. This reflects the fact that data loss is a serious problem for climate, and it may take some months to recover data from a remote site. This is particularly a problem with data losses that span extended periods, though frequent short-term losses are problematic also. At present some countries (e.g., USA) meet this need well, but many if not most countries do not have such backup arrangements in place.
- It is recommended NMHS have in place a network monitoring system that identifies when expected data are not being received, and in the case of AWS, an automated advice that transmission has been lost. This applies also to monitoring ingestion into the climate database. We are referring here to significant disruptions, not an advice every time a one-minute message from an AWS is missed. Where an outage of an AWS is detected, CCI would encourage NMHS to recover the data as expeditiously as possible, whether by automatic retrieval means or physically visiting the site and downloading the data.
- It is recommended that, where possible, high-value stations be equipped with either multiple or redundant sensors (if AWS), OR by collocating AWS and manual observers, OR by some other AWS backup facility. This minimises the risk of data loss, while serving as a cross-check on, e.g. sensor drift.

Ensure adequate standards, metadata and documentation

- More efforts should be made to rigorously capture and archive metadata about observational procedures and instrumentation. This is to support standardization, enable homogeneity assessments, and ensure data provenance and fitness for purpose. A minimum set of metadata requirements is specified in the *Guide to Climatological Practices* and reproduced here at Annex 2.
- Observational methods and practices should comply with recommendations from CIMO. Where this is not the case, any differences from normal standards should be documented as part of the metadata. We are aware that some NMHS countries deploy sub-optimal equipment (e.g., lower cost radiosondes). While it is appreciated that a cost-effective balance needs to be found, we believe that the advantages of using standard equipment should be communicated to NMHSs.
- Similarly, changes in observational programs should be rigorously documented and the documentation retained as part of the metadata. Two examples from Australia serve to illustrate the importance of this:
 - the method of recording phenomena (e.g. “thunder heard”) changed several times over the period 1950s through 1980s, with documentation of the changes uncoordinated and in some cases unable to be found. The recorded frequency of thunderstorms over time was significantly affected by these changes;

- the method of evaluating minimum and maximum temperatures changed fundamentally, from a 9am to 9am reporting period to a midnight-midnight reporting period during the 1950s, then back to 9am-9am in the during the 1960s. Analysis shows this led to a significant bias in average minimum temperature at some mid-latitude stations, with implications for climate change monitoring.
- If changes are made to the times of observations across the network there should be trials at a basic network of representative stations to enable the effects of the change to be documented. Similarly, there is a need to record, as part of the metadata, over which periods daylight savings applies.
- Overall it is strongly recommended that changes only be implemented if there is clear benefit, and the costs to activities such as climate change monitoring are factored into the associated cost-benefit analysis.

Fitness for purpose in extreme conditions

- Instruments need to be sufficiently robust to be able to accurately sample extremes. This means, for instance, that rain gauges in areas prone to heavy rainfall will not easily overflow; that anemometers in cyclone-prone areas are able to withstand wind-speeds in the hundreds of kilometres an hour without being destroyed⁵; that the electronics of automated systems can withstand EMPs from lightning strikes. More generally, the demand for information on extremes is increasing, as is the need to measure them accurately.
- Similarly, in very dry or very moist climates where the dewpoint often falls to very low values or alternatively relative humidity is consistently over 90%, it is important for some climate applications⁶ that instruments be able to reliably measure these extreme values. It is noted here that some measurement methodologies are inherently limited in their ability to sample extremes, for instance, some automated humidity devices are not designed to measure extreme high or low humidities. In view of the increasing need to be able to monitor extremes, it is recommended that instrument manufacturers be pushed to improve their sensors.
- NMHS should be alert to the need to provide extra maintenance during extreme conditions, for instance a TBRG may be fouled by debris in the funnel during severe rainfall events. A rapid response capability to outages is required to minimise data losses.
- As a general requirement illustrated by the previous point, laboratory testing of instruments must be carried out over the full operational range before they are deployed. The climate program views laboratory testing as necessary, but not in itself sufficient, to avoid potential inhomogeneities, and argues that parallel field trials are still required where there is significant change capable of introducing inhomogeneities into the climate record, especially at GCOS sites. It is recommended that such trials be closely discussed between climate users and network operators.
- There is a large and acknowledged gap internationally in the ability to reliably measure solid precipitation at high latitude or mountain locations. The Climate program has a need for accurate measurements of snowfall, snow depth, and rain water equivalent, and for certain purposes, data on ice accretion. Such information is needed at all time-scales, but

⁵ For instance in Australia during the 2010-11 La Nina summer rain-gauge overflows of the standard 203mm gauge were frequent, resulting in a loss of information about extreme events, while early failure of the anemometer at Willis Island during the approach of Category 5 cyclone Yasi (which passed across the island) meant that a rare opportunity was lost to collect data from an extreme cyclone event.

⁶ This may be important for other service provision as well. In Australia, extreme fire weather situations are usually accompanied by very low dewpoints, yet the algorithm in the most commonly-deployed AWS does not reliably measure Td below minus 10.

at least daily. Solutions should leverage new technologies and techniques for making *in situ* and remotely-sensed observations, and research is needed to integrate the two types of observations. AWS should be equipped to withstand icing, and solutions found to accurately measure solid precipitation, whether by equipping them with heating elements to melt incoming precipitation (noting the need to manage possible losses of precipitation due to evaporation), or the use of weighing sensors. Consideration should also be given to equipping key stations (e.g. GCOS stations) with the best available technologies for accurately measuring solid precipitation (e.g., in the US Climate Reference Network snow fences are employed).

Communications and robustness (AWS).

- Observational sites, especially automated systems, require reliable and robust communications and technical support, to minimise data loss. This is frequently a problem in developing and least-developed countries where communications infrastructure and support is often weak or non-existent and often high cost.
- Climate requirements for siting, maintenance and robustness of power supply to AWS are the same as those recommended by the ET-AWS. (WMO, 2010)

Systems software

- The design of PC-based or Web-based data entry software systems for observers should be intuitive, and contain on-site quality checks. This is to minimise the likelihood of observer errors, which can increase quality control loads and adversely affect the quality of the climate record. Again the design and implementation of such software should be subject to user-acceptance testing by NMHS climate staff. The future deployment of smart technologies could also provide some benefits in the gathering and submissions of data.
- It is an acknowledged problem that manufacturers for AWS are reluctant to release their proprietary algorithms, for commercial reasons. However there is a need to obtain at least a minimum level of detail about how quantities are evaluated, particularly where there is a risk of inhomogeneities. For example, sampling period, instrument response period, or number of observations from which, e.g. a one-minute value of a climate parameter is estimated. It is recommended that an agreed minimum level of disclosure of algorithms be negotiated with suppliers. Beyond this, there may be merit in specifying preferred algorithms, sampling periods, etc and only buying equipment that met those requirements.
- Where possible, standardised and stable AWS platform and data processing systems should be aimed for to minimise data and system inhomogeneities

Atmospheric chemistry

- The need to monitor levels of various atmospheric constituents (e.g., Greenhouse gases such as CO₂, methane, ozone, nitrogen oxides; various components of aerosols; reactive gas species, radionuclides, as well as ultraviolet radiation levels) is evident for climate change-related work and indicated in the SoG. These are needed from an adequate surface-based network and from remotely-sensed platforms that monitor stratospheric as well as tropospheric constituents. Noting that the stratosphere is being increasingly recognised as influencing tropospheric climate patterns (via, e.g., the Southern Annular Mode), there is a need for sustainable basic climate observations in the stratosphere.

2.3 Strategic, including network planning.

Network needs and deficiencies

- Planning of observation networks should bear in mind the long-term sustainability of observations from a particular network or site. Every effort should be made to keep stations with long records and/or climate significance open. Similarly, there is a preference for siting future high quality (or “Principle”) climate stations in pristine locations where developmental or commercial pressures are unlikely to force changes that have homogeneity issues. For

instance, while siting stations at airports obviously suits the provision of aviation services, there is a risk that the homogeneity of sites at such locations will be affected by the growth of the airport, changes in runways, etc. Government or protected sites such as national parks would be preferable, particularly for the purposes of monitoring climate variability and climate change.

- There needs to be a sufficient density of stations capable of measuring non-Essential Climate Variables as outlined on page 1. As the SoG makes clear, many climate applications and services make use of these observations, which are also needed for products like climatologies, climate modelling and for ground-truthing remote sensing and automated systems on an ongoing basis. For instance, at the recent WCRP Open Science Conference in Denver, USA (October 2011), presentations during the session on climate modelling indicated that parameterisation of low clouds was a major challenge. Yet observational programs in many NMHS are moving in the direction of fewer observations of cloud type, height and amount. These needs have implications for network planning, as discussed further below.
- For many climate applications there are significant network gaps, especially in areas of harsh climate or forbidding terrain. Where it is feasible, stations should be established to fill in the gaps as needed (possibly funded by discontinuing redundant stations elsewhere). In the harsher, more isolated environments, it is recommended that, along with AWS, space-based observing systems be employed to cover these gaps: a blending of in situ surface analyses and remotely sensed data is required to provide the optimal coverage for climate monitoring activities. Assimilation of the data schemes is required, through NWP-like data assimilation methodologies. While many countries will not possess the capability to incorporate remotely-sensed data, the Regional Climate Centre (RCC) concept may provide the necessary framework for accessing and analysing the data on behalf of all NMHS within the Region.
- To make effective use of satellite imagery and other remote-sensing systems it is essential that:
 - there be adequate ground-truthing against surface stations and radiosonde sites. The existing RBCN networks will in most cases provide sufficient coverage for this work, but where gaps exist in this coverage, NMHSs are encouraged to install stations that fill gaps. Similarly, reference radiosonde stations (e.g. GRUAN) could be used to provide ground-truthing.
 - robust sensor intercomparisons occur. This includes calibration activities, and traceability to a stable standard, to enable the effects of orbital drift, diurnal variations, etc to be identified and corrected for. The aim is to arrive at an integrated time-series of overlapping satellite data. Again such intercomparison work might be most efficiently carried out at specialist centres of excellence. To ensure the long-term sustainability of observations need for climate purposes, there needs to be:
 - a long-term commitment to space missions by space agencies;
 - Effort to minimise changes in sensor;
 - thorough documentation and intercomparison where sensor changes do occur

Managing automation

- High frequency data (hourly down to one minute) is becoming increasingly sought after for climate applications, however full and unmanaged automation contains numerous potential pitfalls for the Climate Record. Network planners should consider the potential benefits of blending AWS and conventional surface observations, noting the complementary strengths and weaknesses of the two types of systems (this is covered in more detail in CCI's "*Guide to the use of AWS for Climate Purposes*" (manuscript in preparation).

Maintenance and calibration

- An adequately resourced inspection, maintenance and repair program. This is especially relevant for AWS in remote areas where there is less likely to be spatial redundancy. The *Guide to Climatological Practices* specifies that Principal Climate Stations (i.e., those of major importance such as GCOS stations, or stations supporting significant services) should be inspected at least annually, and other climatological stations and precipitations stations at least every three years. AWS should be inspected every six months, though again where resources are an issue, priority would be given to the higher-value stations for climate purposes. Routine, non-specialist maintenance such as grass-cutting and cleaning of instruments also to be performed (preferably weekly), where possible by trusted local personnel.
- Similarly, regular calibrations against travelling standards are required to ensure there has not been sensor drift, and to provide a reference where instruments are replaced. It is important that some record of these should be kept as part of the metadata. Automation of this process, and/or the use of multiple sensors, may assist with this calibration process.

Training needs

- Training of observers and adherence to sound observational practices is, of course, needed for all meteorological applications, and in the case of climate if not done will cause increased quality control loads and increases the incidence of poor data. This is especially the case with visual observations, which are particularly prone to subjective error. Performance monitoring and mentoring of observers is encouraged, particularly where quality assurance procedures indicate systemic errors.
- Observer training must emphasize routine maintenance of instruments, and inspections accompanied by remedial training where poor or misguided observational or maintenance practices are indicated. For instance, failure to regularly change the wicks on wet bulb thermometers may lead to artificially high dewpoints as the wick dries out. In countries subject to frequent dust-storms, such as Australia or the Middle East, there may be problems with dirty wicks.
- There have been cases where a loss of knowledge has led to suspension of certain types of observations. For instance, this was a recent problem in Papua-New Guinea where NMHS staff reported they did not have the know-how to release radiosonde balloons. This points to a broader general need to establish a Capacity building strategy aimed at improving standards in observations and data management in Developing and Least-Developed countries, as well as providing access to expertise for the maintenance and repair of AWS. This is particularly pertinent to GCOS stations, and stations supporting major climate services. Such problems may be managed by the intervention of staff from nearby developed countries, through bilateral training and/or technology transfer programs, and/or as an element of WMO's Capacity Building strategy.
- There is a need to ensure observations are actually logged or transmitted, and that field books or rainfall sheets are regularly collected or forwarded to the central NMHS for processing and archival. In some countries where paper records have not been onforwarded, loss or destruction of the records has occurred.

Other needs and considerations

- Observations are needed to support development of renewable energy sources (e.g., feasibility studies). However network planning should take into account that observations taken near renewable energy installations (e.g., wind farms, solar energy systems) may be impacted by the infrastructure itself, and thus be unrepresentative of the conditions they measure. The SoG contains some examples of this.
- There is a need for more daily and hourly observations in and around urban centres, to support climate service provision (e.g., insurance claims validation), research into urban

climate and climate change adaptation, research into the effects of urbanisation, and verification of local NWP and air pollution forecasting. This includes both conventional meteorological observations as well as measurement of chemical variables such as sulphur dioxide and oxides of nitrogen. (*Note that the Guide to Climatological Practices permits a level of flexibility in the siting of urban stations and instruments, but emphasising the need for appropriate metadata*).

- Some countries are well endowed with enthusiastic and conscientious amateur weather observers, and/or Government agencies that establish their own observational networks. Noting the value of high density observations for certain types of climate products or analyses, there may be scope for NMHS to encourage submission of such observations. This is done already in some countries with Storm-Spotter networks, etc. Such observations may or may not become part of the official climate record. To ensure that such data are fit for purpose, NMHS climate and observations programs should provide guidance about minimum observational and metadata standards, particularly in relation to AWS. The development of formal partnership agreements between the NMHS and entities such as government agencies, private companies and universities in regard to data is recommended.

3 Data Management-related

- Given that all climate services depend on accessible climate data, there is a need to support Data Rescue initiatives aimed at securing, inventorying and digitising climate data. This is encapsulated in the following statement from documents tendered at Cg XVI:

The SBSTA further noted the importance of historical observations as the basis for analysis and reanalysis and encouraged Parties and relevant organizations to increase their data rescue and digitization of historical observations and to establish and strengthen international coordination initiatives for these activities

There are various projects and multilateral initiatives under way around the world to support this, and the CCI through its TT-Data Rescue (TT-DARE) is endeavouring to summarise these activities, and provide guidance on best-practice Data Rescue techniques.

- Where digitisation or imaging of records is not feasible due to budgetary or other constraints, every means should be employed to ensure that paper records are stored in non-perishable boxes and clearly labelled and secured. Also, data stored on perishable or obsolescent-prone media such as tapes should be migrated to more modern formats in a systematic way.
- Observational data flows and content must be checked with Climate Data Managers to ensure that all data are arriving in a form capable of being ingested and used. In particular, where once-manual observations are replaced by automated systems, or paper-based records are replaced by electronic logging, great care should be taken to ensure:
 - data flows do not lead to modifications or loss of the basic input data before they are archived, unless the modifications are clearly captured in an audit trail;
 - Software bugs in automated observing and transmitting systems do not cause data to be lost or overwritten. This requires careful monitoring by the NMHS Climate program, observing program or both, whenever system changes are made;
 - Where paper-based forms are superseded by electronic forms, that no loss of the basic data or metadata occurs;
 - There is adequate data provenance, so that information on, e.g., quality control processes is available. In line with good data management practice, this means the

climate community must provide data stewardship of the “raw” data as well as post-ingest or quality controlled data. ISTI⁷ recommends discrete archiving of each level of data processing through the data life cycle.

- This multi-tier approach to data archival also needs to enable users to determine what values were present in the database at a particular time. This is to enable NMHS to answer questions such as: When (NMHS) issued climate statement XYZ, on which data did it base its analyses?
- It is recommended that end-to-end quality assurance processes be established within NMHSs. From a climate viewpoint, this means that the data should be subject to quality control, and procedures should be in place to routinely communicate information about problems in the observational network or related systems to Observation Managers. To support the climate program, Observation Managers need to have in place procedures to respond to problems in a timely manner.
- Noting that for many purposes extremes are highly important, care should be taken to ensure Quality Control processes do not “smooth out” or eliminate extremes, whether at the point of observation (especially AWS) or in subsequent delayed-mode QC.
- There are strong arguments for climate data management systems to have the ability to archive data from multiple sensors:
 - to facilitate redundancy of sensors (as outlined above);
 - to support intercomparison studies;
 - to facilitate the testing of new sensors;
 - to enable archival of data from different instruments, both for intercomparison as above, but to serve different needs (e.g., manually-read raingauges versus automated Tipping Bucket Range Gauges).

4 Other Considerations

- The broader *Statement of Guidance for Climate* highlighted the importance of NMHSs collecting data on non-climate impacts, to better tailor products and services through analysis of impacts. There is an identified need for more paleoclimatic data; collecting phenological data; and on impacts (e.g., in the health area, heat-related deaths, and epidemiological data), to assess sensitivities of populations and systems to climate extremes. This requires investment in data collection activities in these areas.
- The need to improve the submission of CLIMAT messages for climate monitoring. The CCI, through its ET-CDMS, is addressing this through specifying automated CLIMAT generation functionality as a recommended feature of Climate Data Management Systems.
- The need to share climate data, especially the longer-term records, to enable greater scientific understanding in areas such as climate variability and change. While WMO’s Resolution 40 provides a regulatory basis for the exchange of current observations, it does not extend to historical climate data. A supplementation of Resolution 40, raising the sharing of historical climate data to the status of a WMO Regulation, is needed, and has been drafted by CCI. The aim is to have the next WMO Congress adopt as a WMO regulation that NMHS agree to exchange their historical climate data.

5. References (this Section needs more work).

Ref on standards for data completeness.

⁷ International Surface Temperature Initiative

WMO, 2010. *Expert Team on Requirements for data from Automatic Weather Stations, Sixth Session* (Geneva, Switzerland, x-y May 2008) – Final Report. xpx.

WMO, 2011. Guide to Climatological Practices, 3rd Edition. *WMO No 100*, 117pp

Annex 1 – The GCOS Climate Monitoring Principles and Satellite Supplement.

The impact of new systems or changes to existing systems should be assessed prior to implementation.

2. A suitable period of overlap for new and old observing systems is required.
3. The details and history of local conditions, instruments, operating procedures, data processing algorithms, and other factors pertinent to interpreting data (metadata) should be documented and treated with the same care as the data themselves.
4. The quality and homogeneity of data should be regularly assessed as a part of routine operations.
5. Consideration of the needs for environmental and climate monitoring products and assessments should be integrated into national, regional, and global observing priorities.
6. Operation of historically uninterrupted stations and observing systems should be maintained.
7. High priority for additional observations should be focused on data-poor areas, poorly observed parameters, areas sensitive to change, and key measurements with inadequate temporal resolution.
8. Long-term requirements should be specified to network designers, operators, and instrument engineers at the outset of system design and implementation.
9. The conversion of research observing systems to long-term operations in a carefully planned manner should be promoted.
10. Data management systems that facilitate access, use, and interpretation of data and products should be included as essential elements of climate monitoring systems.

11. Constant sampling within the diurnal cycle (minimizing the effects of orbital decay and orbit drift) should be maintained.
12. Overlapping observations should be ensured for a period sufficient to determine inter-satellite biases.
13. Continuity of satellite measurements (elimination of gaps in the long-term record) through appropriate launch and orbital strategies should be ensured.
14. Rigorous pre-launch instrument characterization and calibration, including radiance confirmation against an international radiance scale provided by a national metrology institute, should be ensured.
15. On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored.
16. Operational production of priority climate products should be sustained, and peer-reviewed new products should be introduced as appropriate.
17. Data management systems needed to archive and facilitate user access to climate products, metadata, and raw data; key data for delayed-mode analysis should be established and maintained.
18. Use of functioning baseline instruments that meet the calibration and stability requirements stated above should be maintained for as long as possible, even when these exist on decommissioned satellites.
19. Satellite intercomparisons with ground-based baseline observations are necessary to enable calibration of the satellite data.
20. Random errors and time-dependent biases in satellite observations and derived products should be identified, and rigorously documented.

Annex 2 – Basic metadata requirements (from 2011 edition of Guide to Climatological Practices, Chapter 2).

Basic station metadata should include station *name* and station *index number* (or numbers); *geographical coordinates*; *elevation* above mean sea level; *administrator* or owner; *types of soil*, physical constants, and profile of soil; *types of vegetation* and condition; *local topography* description; description of *surrounding land use*; *photographs and diagrams* of the instrumentation, site, and surrounding area; *type of AWS*, manufacturer, model, and serial number; *observing programme* of the station (elements measured, reference time, times at which observations and measurements are made and reported, and the datum level to which atmospheric pressure data of the station refer); and *contact information* such as name and mailing address, electronic mail address, and telephone numbers.

Documentation should contain a *complete history of the station*, giving the dates and *details of all changes*. It should cover the establishment of the station, commencement of observations, any interruptions to operation, and eventually the station's closure. *Comments from inspection visits* (see 2.6.6) are also important, especially comments about the site, exposure, quality of observations, and station operations.

Instrument metadata should include *sensor type, manufacturer, model, and serial number*; *principle* of operation; *method of measurement* and observation; type of detection system; *performance characteristics*; *unit of measurement* and measuring *range*; *resolution, accuracy* (uncertainty), *time constant*, *time resolution*, and output averaging time; *siting and exposure* (location, shielding, and height above or below ground; date of installation; data acquisition (sampling interval, and averaging interval and type); *correction procedures*; *calibration data* and time of calibration; preventive and corrective *maintenance* (recommended and scheduled maintenance and calibration procedures, including frequency, and a description of procedures); and *results of comparison* with travelling standards.

ATTACHMENT 1

REQUIREMENTS FOR CLIMATE DATA

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(Version 1, prepared 28 November 2009 by Raino Heino, Finland, revised 31 March 2010.

Version 2, prepared William Wright 27 May 2011)

1. INTRODUCTION

This Statement of Guidance (SoG) was developed through a process of consultation within the Commission for Climatology (CCI) community. It documents the observational requirements for climate data in support of the work of the CCI (cf. Appendix 1), the applications and services provided by NMHSs and other climate-focussed institutions, and meeting the needs for data in support of the UNFCCC and the Global Framework for Climate Services (GFCS). The Statement will continue to be reviewed at appropriate intervals to ensure that it remains consistent with the current state of the relevant science and technology.

This report covers comprehensive requirements for climate data for some important application areas. These include climate change monitoring, detection and attribution, climate variability monitoring and seasonal prediction, climate research and modelling, and the provision of a wide variety of climate services, some of which are considered below. A general observation is that the services supported by climate data are essential for many planning and information applications, inform government decision-making, support emergency service operations and vulnerability reduction planning, and address the broader needs of a country's populace for climate information. As such, this statement provides guidance on the data needs for many aspects of the Global Framework for Climate Services (GFCS).

The needs for climate data are not the same across all applications. Climate change detection and attribution do need to be based on high-quality, homogeneous, long-term data. For this purpose the GCOS baseline systems, especially the GCOS Surface Network (GSN) and the GCOS Upper-Air Network (GUAN), are essential benchmarks to ensure the homogeneity of the overall global/regional databases. To meet national needs (including adequate sampling of regional climate variability and vulnerable regions), the high observing and reporting standards and the commitment to continuity and homogeneity of the GSN should be extended to regional networks such as Regional Basic Climatological Networks (including Reference Climate Stations). Not all climate applications need this level of stringency and completeness, though clearly the better and more reliable the data, the better the services provided. Remote-sensing systems, especially satellites, also have a vital role to play, and need to be effectively integrated with *in situ* observations.

The chief general requirements for climate observations in supporting most climate services and applications is that they be reliable, accessible, as far as possible complete, and long term. They should also be taken using standard observational equipment and practices, and if this is not possible, any differences from standard must be documented. Because many climate services are required in and around major population centres, high quality data are also required from in and around large towns and cities that may not necessarily be suitable for climate change monitoring. Finally, many services and applications described below require access to historical data, requiring in turn that NMHSs participate in data rescue activities where necessary, and have sound climate data management practices.

The most significant variables for most applications are the so-called *Essential Climate Variables*. For surface variables these include temperature, precipitation, mean sea-level pressure, winds, humidity and solar radiation. For many other applications, data on evaporation and evapotranspiration, soil temperatures, and visual observations such as cloudiness and visibility, and phenomena such as thunderstorms, hail, dust-storms, frosts, etc are required, as well as documentation of longer-period phenomena such as heat waves, cyclones, floods and droughts. For most purposes monthly and daily data are required; for many applications hourly and even higher-frequency data are needed. Data archaeology and metadata are also important for climate purposes, and for certain applications other data-sets such as paleoclimatic data, and reanalysis data are required.

Data on variability and vulnerability, and extreme events are essential, for monitoring and managing climate variability and change and their impacts, and for climate change adaptation purposes. The most common and high impact manifestations of local variability involve temperature and precipitation, which show significant variability in most regions, and have marked effects on local and regional economies and livelihoods, including major health impacts. Multi-seasonal anomalies such as those associated with the El Nino-Southern Oscillation phenomena, have very significant effects on society and livelihoods. Seasonal prediction, and advance warning of adverse conditions, is a vital activity that requires access to a range of atmospheric and oceanic observations in near-real time. Multi-year anomalies are less well understood, but can have devastating social and economic consequences.

The importance of sharing the longer-term records of daily and even higher resolution data to enable studies of high impact climate events cannot be overemphasized. Sharing data enables greater scientific understanding and ultimately better products; data owners benefit much more from sharing the data than not. Nevertheless, it has proven much more difficult to create global data sets of daily data than of monthly data. Another important theme that will recur through this document is the importance of data quality assurance, so that analysis and applications can proceed confident that the data are reliable, and not artificially influenced by e.g., changes in the measuring instruments and observing methods/locations, and errors in the data. In this respect, those responsible for Quality Assurance need to consider and act on the findings of CIMO on data issues related to instrument design, and siting of instruments. Quality assurance should also provide a means of providing feedback on climate needs to observational program managers within the NMHSs. More generally, there needs to be a close and ongoing process of consultation and engagement between observation program managers and climate scientists, to ensure climate program needs are met.

The GCOS *Second Report on the Adequacy of the Global Observing Systems for Climate in Support of the UNFCCC (2003)* provided a complete assessment of the adequacy of then-current observing systems, particularly to meet the needs of the UN Framework Convention on Climate Change. An update of progress against this report is available in *GCOS (2009)*. The GCOS Climate Monitoring Principles, which are included therein (and reproduced here in Appendix 2), represent basic requirements that must be adhered to when planning, developing and operating all observing systems relevant to climate data collection, including both *in situ* and satellite-based systems. The importance of adhering to these cannot be overemphasised.

The analysis below concentrates mainly on surface climate variables, although going forward, increasing emphasis needs to be placed on the terrestrial and ocean components of the climate system. Monitoring sea-level variations and rise, for instance, is vital for climate change adaptation efforts in coastal or island communities. Increasing sea levels mean greater risk of storm surge, inundation and wave damage to coastlines, particularly in Small Island States and countries with low lying deltas. In general, however, observational requirements over the oceans, and terrestrial observations, are not dealt with in any systematic way in this version of the Statement of Guidance. Similarly, while not dealt with in detail, it should be noted that the climate program requires access to continued high quality observations of atmospheric constituents, especially Greenhouse gases such as CO₂, methane, nitrous oxides, ozone, etc. These are needed from both surface-based *in*

situ networks, and from remotely sensed platforms, that monitor stratospheric climate and atmospheric constituents.

2. USER REQUIREMENTS

This section, as originally developed in 2009, was shortened and modified from the document "Observation needs for climate services and research" describing the needs for climate data in community sectors identified for consideration at the World Climate Conference (2009). Subsequently this section was reviewed and considerably modified in 2011 by climate applications experts of CCI, particularly those of OPACE 4, under the guidance of the CCI Task Team on User Interface led by Dr Roger Stone (Australia) (see Appendix 1). Please note as well that there are related SoGs to which a number of these texts are cross-referenced, including the SoGs for Hydrology and Agricultural Meteorology and can also be guided by the IGOS/Cryosphere Theme⁸.

What follows is a brief summary of the climate data needs for various major activities. Underpinning these are some general principles that highlight the particular needs of climate data.

- Climate data needs to be securely managed, with emphasis on accessibility in electronic forms. Therefore, data flows from observing systems to climate databases, and quality assurance programs, need to be adequately planned and resourced.
- Historical data is required for most climate applications, accompanied by easily accessible, and as far as possible complete, metadata.
- Observational systems must be capable of functioning and reliably recording extremes of climate commensurate with each countries' needs. This includes, for instance, suitable instrumentation for cold climates, ensuring raingauges do not overflow in heavy rain events, and that automated systems are equipped with surge protectors and data loggers.
- Increased public scrutiny of climate data collection, processing and management means that defendable, best-practice, well documented standards are required to support the climate record of a country, including observational practices.

Human health

Climate has a known and demonstrated effect on human health. Thermal extremes (warm and cold) are well known to cause large increases in mortality. Hot weather extremes, which may increase under climate change, appear to have a more substantial impact on mortality than cold wave episodes. Research indicates that mortality during extreme heat events varies with age, sex, and race. Other factors associated with increased risk from heat exposure include alcoholism, general health, and living on higher floors of buildings. Humidity has an important impact on mortality since it contributes to the body's ability to cool itself by evaporation of perspiration. In addition, humidity affects human comfort, and the perceived temperature by humans is largely dependent upon atmospheric moisture content.

Other relatively short-period phenomena, but which are nevertheless associated with climate variability and change, also have the capacity to have potentially adverse effects on human health. Fluctuations in the frequency and severity of weather and climate extreme events such as floods, droughts, tornados, storms, avalanches, hail, lightning strike, etc., would have obvious impacts on morbidity and mortality rates. Major fires also fall in this category. These, and major volcanic events, in turn have the capacity to affect climate through the introduction of aerosols into the atmosphere and through land-surface changes, which can have major air-quality and albedo consequences. In this regard, climate change might affect the frequency of large fires in a region which then leads to longer term land-surface changes and changes to other climate parameters, besides climate induced health issues. A combination of satellite and *in situ* data will be needed to permit characterization and modelling of the induced atmospheric anomalies. The ability to model dispersion patterns of these pollutants, along with other hazardous airborne substances such as nuclear radiation or toxic chemicals, is required, based on detailed knowledge of, and projections of, low- and high-altitude winds.

Climate conditions can also contribute to, and exacerbate, epidemic episodes of significant infectious diseases, through changes in the distribution of insects and animals that may carry

⁸: IGOS, 2007. Integrated Global Observing Strategy Cryosphere Theme Report - For the Monitoring of our Environment from Space and from Earth. Geneva: World Meteorological Organization. WMO/TD-No. 1405. 100 pp. - http://cryos.ssec.wisc.edu/docs/cryos_theme_report.pdf

human and animal diseases, and through changes in water quality. Climatic conditions can also be linked to other morbidity effects associated with pollen concentrations and high pollution levels, the latter also being linked to changes in cancer rates. Weather and climate conditions have demonstrably been linked to changes in, for example, outbreaks of pneumonia, influenza, bronchitis, and other respiratory diseases, and can affect birth rates and sperm counts. Humidity has an important influence on morbidity in the winter because cold, dry air leads to excessive dehydration of nasal passages and the upper respiratory tract and increased chance of microbial and viral infection.

As many health effects tend to be quite localised, it is important that climate observations are maintained and improved at local scales, especially in urban areas. These climate observations include not only physical variables such as temperature, rainfall and humidity (which would be required on at least a daily basis), but also chemical variables (e.g. sulphur dioxide, oxides of nitrogen and isotopic concentration of precipitation), and aerosols. Such observations need to be analysed in conjunction with concomitant health data, including epidemiology data related to morbidity and mortality, and more generally with surveillance data related to the impacts of climate variability and change.

Energy

Energy plays an important role in human development, and the standard of living of the earth's citizens. Climate extremes and trends influence the energy demand as temperatures rise and fall, but also the planning of energy infrastructure depends on climate and future climate scenarios.

Extreme climate and weather variability are capable of triggering disasters in the energy sector, with the magnitude of the impacts dependent on the type and size of energy system and the degree of impacting climatic elements. Overhead power lines for the distribution of electricity are vulnerable to a number of weather hazards. The greater proportion of power supplies interruptions are linked to lightning and thunderstorm activities, and strong winds. However ice accretion is also important in some colder areas. High humidity also affects the efficiency of electrical transmission and the performance of insulators. Heavy rains may disrupt the availability of essential fuel products such as cooking gas and other fuels, especially to isolated areas when roads become impassable.

The demand for fuel and electrical power is in turn sensitive to weather conditions, with extra power required for heating during cold weather conditions, and for cooling in hot weather. To estimate natural gas/coal consumption in relation to weather conditions, for example, it is necessary to have reliable historical climate data. Heating/cooling day degree studies can be used as a tool to reveal this relationship.

For planning and analysis purposes therefore, information is required on rainfall, temperature, winds, extremes in these variables, as well as humidity, snow, ice loadings, and thunderstorm (or lightning) frequency. Ideally, these data will be incorporated into sensitivity analyses that relate the intensity of these climatic phenomena with impacts on systems.

Information from weather forecasts is currently routinely employed in the energy sector (from energy producers to suppliers, and from financial analysts to national regulators) to assist in decision-making. This information is used for several purposes, e.g. for pricing the cost of energy or that of financial instruments (e.g. derivative contracts). Other climate information, such as that from seasonal and decadal forecasts, is also starting to be included in decision processes in the energy sector. This weather/climate information, especially when severe conditions are expected, will likely become a regular factor in both Climate Risk Management and in climate change adaptation strategies, including in the formulation of climate change adaptation regulations. In addition, weather/climate information will be a key element in the development and use of renewable energy resources such as wind, solar energies, biofuel, heat pumps and hydro power. This points to the need for suitable data in real-time to support weather forecasts and real-time

weather monitoring, as well as long-term climate data to support predictions and the development of climate change projections.

Climate may affect all sectors of power economy including energy generation (both traditional and renewable energy sources), transportation and consumption. Climate change is likely to have a significant impact on energy demand (positive - less heating requirements; negative - more cooling required). Exploration and exploitation of oil and gas fields for example, and design and operation of oil and gas pipe-lines require a set of tailored climate products. Historical and ongoing data on air temperature, humidity, wind speed, snow and ice loadings at suitably representative sites, are required, as well as statistics on the probability of dangerous weather events. These are necessary for the design and safe operation of nuclear and thermal power stations and electric power lines.

Hydro-electricity is a source of energy in some mountainous areas. As climate change and variability affect the seasonal cycle of snow and glacier melt, and wind and precipitation patterns change (especially drought occurrence), the operation of such power plants will be affected. Renewable energy sources (wind and solar power) and their efficiency are clearly dependent on climate information, both for selecting sites for infrastructure and for sustained operation. Decadal-scale and longer-term climate fluctuations or climate-change shifts may affect the long-term efficacy of wind and solar power sources in some regions. Climate information is also needed for the design of energy efficient buildings for all seasons as well as for decision-making on where best to locate biofuel sources. Extreme climate conditions such as heat wave and cold surge could adversely affect the efficiency of energy supply. Climate prediction information is also needed for the management of some forms of energy supply (e.g., drought effects on hydropower generation).

Therefore data requirements for the energy industry include: daily and monthly data, and extremes, of precipitation (including snowfall), temperature, wind speed, direction, and wind-run, along with data on cloudiness, and sunshine hours (or solar radiation data). Data such as winds, sunshine hours and radiation can be sourced from both *in situ* measurements and satellites. There is also a need for data on terrestrial/hydrological variables such as glacier extent and mass, and lake and storage measurements. This refers to both historical and ongoing data, which needs to be robust to ensure effective data on accumulation.

It should also be noted that while renewable energy sources (e.g., hydro-electricity, solar, wind power) present an opportunity for the production of clean energy, some solar energy systems may impact upon the local climate. For instance, parabolic trough types of Concentrated Solar Power (CSP) solar energy systems can create a local heat island effect (to produce 50MW electricity power with CSP requires between 126 - 225 hectares of land and 600,000 - 800,000 m³ water, and an operating temperature of between 250°- 650°C). Operational wind farms can generate both turbulence and wind 'shadows' which are a hazard for small airstrips. This points to the need for both careful monitoring of local climate, and data for risk assessments. In the case of wind farms, for instance, there is a need for surface and low level wind data from both satellites and in-situ sites (satellite-derived wind data at land-based locations, as opposed to over the oceans, are probably not as accurate as *in situ* observations, but are useful for pre-feasibility wind resource estimation). Measurements of natural turbulence in the atmospheric boundary layer are also required. Highly useful information is contained in reanalysis products such as those from the ECMWF, NCEP, JRA, the UKMO ACRE global data reconstruction project, satellite observations, and other remotely sensed data from LIDAR-and SODAR-systems.

Fresh water (see also the SoG for Hydrology, and guidance from the IGOS/Cryosphere theme for more detail)

Fresh water/terrestrial-surface-water resources are essential for health and well-being. As well, they exert a strong influence on the sustainability and future development of most communities, and also influence societal decisions on water rights and water use, both within a nation's territory and among regional neighbours. These are obviously critically dependent on climatic factors. Similarly, climate information is essential in dealing with, and formulating management policies for, hydrological disasters. Increasing climate variability (due to climate change), manifested through

increased frequency and severity of both floods and droughts, and exacerbated by increased evaporation rates due to rising temperatures, is already having disastrous impacts on the availability of fresh water supply. This is particularly evident in Sub-Saharan Africa. To a lesser extent, rainfall and evaporation groundwater resources are also influenced (but with a considerable time lag).

Historical and ongoing rainfall and evaporation data, along with systematic observations of other basic atmospheric variables such as temperature, wind, and the various components of solar and terrestrial radiation, are vital for assessing overall water balance, planning effective hydrological disaster management strategies, and for planning responses to interannual and longer-term variability, and climate change adaptation (e.g. are extra storages needed?). Observations of key hydrological variables such as streamflow, lake-levels, soil- and groundwater levels also contribute to these activities, by contributing to knowledge about the storage and movement of water at the land surface. Increasing emphasis needs to be placed on monitoring the quantity and quality of ground water storages and their changes, especially given the increasing use of ground water resources for human consumption in many parts of the world. All the above data are also useful in the management of watersheds, an emerging key issue as climate change contributes to land degradation and water scarcity in arid and semi-arid regions, and in improving water harvesting in both rural and urban areas. In each case information across a range of space- and time-scales, and on high and low extremes, is required across the components of the water cycle. Data are also required to enhance methods for extrapolating into hydrologically information-sparse areas. At least some observations should be taken of chemical parameters in precipitation (e.g. sulphur dioxide, oxides of nitrogen and isotopic concentration). Among the applications are estimating water quality and source.

Since both glaciers and snow water equivalent (snow depth is often used to estimate snow water equivalent, if the density is known) are important features in the hydrological cycle and affect fresh water supply for many regions, systematic observations to monitor variability and changes in these parameters are vital. Remote sensing observations are ideal for mapping characteristics of these parameters. The long-term contributions to run-off from glaciers and snow should be modeled from mass balance studies based on sound historical records.

Sustainable cities

In many countries, the trend is towards increasing urbanisation. Thus, the impacts of climate variability and change on urban areas need to be well understood. In addition, the impacts of urbanization on climate variability and change also need to be understood. Among the issues pertinent to enhancing sustainability and liveability of cities are:

- The impact of urbanisation on local and regional climate;
- The effect of building design on adaptation to climate changes;
- The effect of urban planning in optimizing energy use, especially for transport;
- Human health impacts of air quality through increasing air pollution⁹, and physical climate changes such as increased frequency or severity of heat waves;
- Effectiveness of urban planning to optimize management of water supply, and prevent flooding, especially for cities with large populations;
- The effectiveness of urban planning to facilitate adaptation to sea-level rise including aspects associated with more severe storm surge events,
- The effectiveness of catchment and watershed management, and neighbouring forest management, to provide security against flood, water shortage and fire risks.

To achieve these things, detailed climate observations (i.e. temperature, precipitation, wind,

⁹ Air pollution is an important issue. There is a close relation between air pollutants (between SO₂, PM₁₀, NO, NO₂, CO) and climatic factors such as temperature, atmospheric stability and wind.

humidity, solar radiation, atmospheric aerosols and pollutants) are required, while for disaster mitigation and infrastructure planning, streamflow, river heights and flood levels, sea level, storm surge, storm tracks, water quality, etc) are also needed. The value of this information is enhanced if combined with associated socio-economic data. Within urban areas, the density and frequency of observations are particularly important for developing optimal strategies for managing climate impacts.

Food production and agriculture *(see also the SoG for Agricultural Meteorology for further information)*

It has long been understood that climate exerts a fundamental control over agricultural production and distribution processes that feed the world's population. Proper and efficient use of natural resources for sustainable agriculture depends on effective use of climate (and weather) information. WMO Members meet this need by providing accurate weather and climate observations, analyses and forecasts, including seasonal predictions, for the agricultural community, which helps increase crop and livestock yields, plan planting and harvest time, optimise cropping strategies, and reduce pests and diseases. (Source: http://www.wmo.int/pages/food_security/index_en.html) Increasingly they also need to respond to the challenges of long-term climate change.

Climate change, and the associated increasing frequency of climate extremes around the world, pose current and likely future threats to agriculture and food security. Moreover, increasing demand for food by an ever-increasing world population, the rising demand for biofuels, and limited land availability, increasingly forces agriculture into more marginal producing areas. Together these increase the risk to agricultural systems from natural hazards, such as droughts, floods, heat waves and freezes, especially in marginal cultivation areas. Climate factors such as the above also influence animal husbandry, fisheries, and the spread of disease in plants and animals. A recent IPCC report states that increases in daily temperature will likely increase the frequency of food poisoning, particularly in temperate regions. Collectively these factors contribute to socio-economic pressures, with downstream effects on commodity trading markets; and impact significantly on global food supplies and global food security issues. Some issues affecting food security are summarised in Attachment 3.

A responsive and sustained regional and global monitoring network of all the surface Essential Climate Variables (precipitation, temperature, winds, radiation balance), along with evaporation, is required to ensure early alerts of extreme events such as floods, heat waves, freezes, tropical cyclones and other climate events for agriculture. This information would also support seasonal predictions of unusual temperature conditions, excessively wet conditions, or droughts. There is a need also for data on soil moisture, and agricultural variables such as crop phenology, to be incorporated into regional and global agricultural forecasting, and decision support systems. Similarly, for improved mechanisms for delivery of short- and medium-range weather forecast information, to help farmers cope with increasing climate variability. This information will help provide early warning of potential herd collapse; or crop failure due to drought, heavy rain, hail, or frost; or conduciveness to disease (plant and animal). One issue that does need addressing is that agricultural producers do not always receive, or make use of, weather and climate information. Therefore, improved communication and dissemination systems are needed to deliver timely and usable information to the agricultural decision makers: improved service delivery and stakeholder engagement needs to bridge the gap between climate service providers and the user communities.

Climate change affects agriculture and food production in complex ways. Direct influences include changes in agro-ecological conditions, production volumes, and even crop viability. The overall impact of climate change on food security will differ across regions and over time, and importantly, will also depend on the overall socio-economic status of a country when climate change set in.

The location of land suitable for grazing or crop production can be expected to change as climate changes, with some regions of the world becoming better suited for pasture and crop production,

or better suited for warmer climate species. Understanding the effects of these changes on food security, and assessing whether food systems can adapt sufficiently to avoid increased food insecurity, will be priority concerns in future. Climate data (all types) is needed to develop relevant projections of the future climate, and of the opportunities and threats to food production that may emerge. Climate data are also needed to support government-level decision making (e.g., drought relief for farmers; decisions on the sustainability of certain land management practices). Long-term monitoring of basic climate variables, related to the fluxes of energy at the surface, is essential to help countries plan for changes in the location, extent and productivity of agricultural and grazing lands.

One final point: there is a need to better manage the “trade-offs” that can occur between managing climate change mitigation and adaptation activities: although ideally these should complement each other, in reality they sometimes conflict. For instance, farm level energy-intensive adaptation responses to water scarcity may run counter to climate change mitigation efforts. Also, farmers could be worse off if they are forced to pay the price of increased emissions resulting from energy-intensive adaptation. At the global level, climate change mitigation practices may result in increased water consumption, including, e.g., using water to sequester carbon; and generating low-carbon energy via technologies such as afforestation, carbon capture and storage, and biofuels. Many climate response policies are destructive for freshwater ecosystems and resources. Therefore, greater understanding of the interdependencies between systems is needed to maximize integration of climate change responses, again highlighting the need for data both on climate and the systems they impact.

Tourism

Tourists, the tourism industry and tourism destinations are sensitive to climate variability and change. For tourism destinations and operators, climate is a major determinant of seasonality, and directly influences, even dictates, many tourism operations that influence profitability, as well as being central to tourism marketing. Climate variability and change can greatly influence environmental resources critical to tourism (e.g. snow in skiing areas), or deter tourists (e.g. higher cyclone risks). For tourists, the climate both at the point of origin and at destinations is a central motivator for travel, a key influence on destination choice, and also been found to influence both tourism spending and holiday satisfaction. Basic averages of key climate parameters at key destinations, chiefly temperature and rainfall, answer many of these questions.

On top of this, the impacts of climate variability and change are far-reaching for some tourism segments and regions, and include:

- Warmer temperatures would affect the seasonality and major geographic patterns of tourism demand, increase heat stress for tourists, alter heating-cooling costs, and could change the range of infectious diseases;
- Decrease in snow amount and extent would increase snow-making costs, and decrease the length of winter sports seasons, making some current destinations unviable;
- An increase in frequency or intensity of extreme weather (e.g. tropical cyclones/hurricanes and related storm surge impacts, and mid-latitude winter storms) would increase risk for tourists and infrastructure, raise insurance costs, and increase the business risks of travel delays and cancellations;
- Reduced precipitation and increased evaporation would create or increase water stress in some destinations, could cause or increase competition between tourism and other water users, could affect availability of locally-produced food, would exacerbate desertification and increase the threat of wildfires, with consequent threats to infrastructure, tourist safety and destination aesthetics and tourism resources;
- Increased frequency of heavy precipitation would increase risk of flooding, affecting safety of tourists and their hosts; increasing risk to tourism infrastructure and to natural and cultural heritage assets, a major draw for destination choices;
- Sea level rise will cause flooding and increase coastal erosion, reduce or eliminate vital beach areas, put significant tourism infrastructure such as waterfronts and heritage assets

- at risk, and increase costs of, and reduce availability of, freshwater supply because of salt water intrusion;
- A rise in sea-surface temperatures would increase risk of coral bleaching (and even the future existence of coral reef systems), and affect marine resources (including availability of marine food supply);
 - Changes in climate could also affect tourism by reducing biodiversity, rendering ecologically-unique species or systems extinct or more restricted in range, and affecting the abundance of key species and their predators). This can be either direct (e.g. change in plant species through changed temperature and rainfall), or indirect (e.g. loss of species through climate-induced environmental changes such as fire frequency, ice distribution, water levels or changes in migration patterns).

Vulnerability to these potential impacts is of particular concern where tourism has become a significant factor in the local and national economy, as is the case in many developing countries and particularly Small Island Developing States. The sector recognizes that climate change will also, in some regions, raise new opportunities, so all components of the sector, in all regions, need to be cognizant of both risks and opportunities associated with climate variability and change, for effective decisions and the sustainability of what is now a major component of the global economy. Priority information requirements for services to the tourism sector would include means, variability and extremes of: temperature, precipitation, sea level rise, sea ice, storm surge, sunshine, solar radiation, humidity, water temperature (inland and ocean), water quality, snow amount and extent, snow depth, tropical cyclone tracks and frequency, flood characteristics, heat wave frequency, and winds. Historical data from all these would also be required to help develop climate change projections, impact assessments, and where possible, adaptation measures.

Ecosystems

Climate is an integral part of ecosystems, and organisms have adapted to their regional climate over time. Climate change is a factor that has potential to alter ecosystems and many resources and services they provide to each other and to society. Human societies depend on ecosystems for the natural, cultural, spiritual, recreational and aesthetic resources they provide.

Therefore, it is necessary to integrate climate change impacts on terrestrial and aquatic ecosystem analysis and projections. Satellite images on land degradation (e.g., NDVI) should be collected and matched over time to climatological data analyses. As in the previous Section, climate data from a wide range of variables with the capacity to affect ecosystems is required for climate change projections. Such data are particularly required at representative locations in ecologically-significant or vulnerable areas.

Coastal erosion is a major concern in many areas, particularly in Small Island Developing States, and could be made substantially worse in the future due to rising sea-levels, and changes in storm tracks and intensities, projected to occur under climate change. Adaptation issues and policies require suitably down-scaled model projections that are “trained” and tuned on the basis of historical data.

Disaster management

Most types of disaster situations are weather and climate related. All countries suffer from meteorological hazards to some extent, but some are more prone than others to socio-economic impacts because of varying levels of vulnerability and resilience to the hazards. Because of economic circumstances, population increase and resulting demand for land, human settlements are sometimes established in disaster prone areas, with far reaching implications for health and public safety. These events have resulted in serious disruption of human settlements endangering life and sometimes accompanied by outbreaks of vector and water borne diseases, famine and malnutrition. It is therefore crucial to factor weather and climate information into the country's disaster management strategies.

The monitoring of seasonal climate conditions is required to accurately predict the possible onset of extreme meteorological/hydrological conditions such as drought and cyclones, and related conditions such as wildfires. Building effective adaptation/mitigation capacity for future events is also dependent on climate data, especially extremes. Apart from observations of the related climatological variables themselves, sea surface temperatures and indices of, e.g., soil moisture are required. Appropriate and reliable meteorological/climate data, in real time, are needed to model the potential danger areas associated with nuclear incidents, and possibly the spread of hazardous substances due to war, terrorism, or pandemics.

The insurance and reinsurance industries and other financial and business entities require access to current and historical climate data to realistically assess risk in their activities, and in the case of insurance, to settle claims equitably. Reliable quality control processes for the data received are crucial here. Data on hazardous meteorological phenomena, such as hail and thunderstorms, and for meteorologically-related phenomena such as dust-storms etc, are also required, and the availability of such data can be placed at risk if automated observation programs are not carefully managed.

General public.

Apart from the above, many climate-sensitive industries and activities rely on climate data and information, from raw observations through climatologies, to seasonal predictions. In many countries the general public and groups such as the media and learning institutions require climate data and information, to satisfy countless needs.

The data requirements to support these are wide-ranging, and include all the essential variables, as well as data on visual observations and phenomena at representative stations. Data required are typically daily and monthly observations; extremes; and long-term averages, but for some applications, may include sub-daily resolutions. Major population centres and socio-economically important locations are likely to be the chief source of such enquiries.

3. BACKGROUND TO OBSERVING CAPABILITIES

This section is based mainly on the World Climate Conference document "Capability of existing and future observing systems" as well as the deliverables of CCI Expert Team on Observing Requirements and Standards for Climate and Expert Teams on various application areas (cf. Appendix 1).

(It should be noted here that observational requirements over the oceans are not reflected in this Statement of Guidance and terrestrial observations are handled in a limited way).

Observing systems - observation types, metadata, etc

The collection and management of climatological data, including ensuring its accessibility in electronic forms, is critical for the development of climatological applications and services, for running modelling applications relating to climate-sensitive activities, and for tuning, verifying and downscaling climate change models. The data are used by, inter alia, the NMHSs, climate analysis centres, climate and sector-based research institutes. It must be noted that climate applications have special requirements not necessarily required for weather services, particularly in relation to continuity, reliability, homogeneity, and sustainability, although the stringent standards required for e.g., climate change monitoring are not necessarily required at all sites and for most other applications.

The adequacy of observational networks varies substantially from region to region, and observations required for some of the applications described are in many areas inadequate in terms of spatial and temporal coverage. In particular, information about large areas with only sparse conventional observing networks (e.g., the vast oceanic areas and sparsely-populated areas of the southern hemisphere) can only be obtained by remote sensing, but effort is required to

ensure such data are effectively integrated with traditional observations. Even then, remotely sensed data may not meet the needs of many users for point-specific data. Both in-situ and remote-sensing observations therefore have roles to play.

The descriptions provided above indicated a host of climate variables required on a variety of time-scales, from a suitable range of representative sites. These include the standard weather elements (air temperature, precipitation, relative humidity, wind speed/direction, solar radiation, soil moisture, evaporation, etc.), noting also the need for visual observations and observations of phenomena not necessarily well sensed by automated systems. It is also important to collect other data e.g. information on disasters (tropical systems such as tropical cyclones and their associated storm surges, severe weather events, floods, fires, freezes, blizzards, ice storms, volcanic activity, tsunamis, and mortality data for heat waves, etc.), along with data on air quality, air chemistry and certain terrestrial variables, at strategically-located sites. To make optimum use of these data for planning and responses in climatically-sensitive activities, data are also required about associated impacts on communities. Successful adaptation to climate change also requires an assessment of how responsive current climate-sensitive systems (natural and man-made) are to climate and its variations; for instance, how much rainfall is required to ensure an adequate water supply. This makes use of historical relationships developed between climate data and impacts.

The longest climate records are available for the more fundamental surface variables, primarily air temperature and precipitation. For studies of climate change there is a requirement that the basic measurements be homogeneous i.e. not affected by changes in instrument type and location or observation practices, or by undocumented data adjustments. NMHSs should give a high priority to maintaining the operations of meteorological observation stations which have long data periods, and to collecting and maintaining environmental and observational systems metadata. Improvements to instrumentation require overlapping observations of the old and the new system for a period sufficient to identify and eliminate time-dependent biases (cf. *GCOS Climate Monitoring Principles, Appendix 2*). Where no overlap exists, a consistent, scientifically-robust method for adjusting data series based on data from neighbouring sites is required.

The GCOS Surface Network (GSN) provides a baseline set of observations against which more detailed national and regional measurements can be assessed. Coverage over land is generally good, but performance is poor in some regions. High-quality national and regional networks of Reference Climatological Stations (RCSs) must be maintained representing, at a minimum:

- Key features of spatial climate variability within a country;
- Stations representing major socio-economic areas;
- Stations representing vulnerable locations.

It is recognized that such maintenance and efforts to ensure the high quality of the data (often solely the burden of the NMHS), have significant cost implications. At present, data from many RCSs may be measured, but do not necessarily make their way to global data centres. There are various treatable reasons for this, among them poor communication systems; and lack of capability in generating the required (CLIMAT) messages. Addressing problems that prevent this sharing would be of immense benefit to the global climate community.

In addition to observations at the high quality RCSs, there would be great benefits to the full gamut of climate services and monitoring activities, if there were increased frequency and density of observations, and greater reliability of observations (in terms of accuracy and completeness), particularly of near-surface humidity; precipitation – including over high-latitude and mountainous areas and oceans; and winds over land regions.

As noted above, to fully meet the data needs of a country or Region, a combination of remotely-sensed and conventional *in-situ* observations is optimal. Under certain circumstances, remote sensing techniques are valuable, and even essential where conventional *in-situ* observations are lacking. Radar images are, of course, highly useful for sensing precipitation locations and intensity, and satellite images are invaluable for mapping areal cloudiness and radiation properties (surface radiation, albedo for instance). Similarly, the different sensors aboard satellites allow sensing of a

whole range of parameters, including cloud heights and depth (through outgoing longwave radiation), surface winds (scatterometer), thermal properties such as surface temperature, evapotranspiration, and atmospheric stability (via vertical temperature profiles), to name a few. Microwave imagers and outgoing longwave radiation measurements provide information on different aspects of precipitation, and provide data on other climatically-significant parameters (e.g., microwave sensing of sea-ice extent). Satellite-borne rain radars offer the potential for improved observations. Geostationary satellites are optimal for frequency of observations; research polar satellites have adequate horizontal resolution, but lack the necessary observing frequency. It must be recognised that there is a requirement for adequate integration of the data from remotely-sensed and conventional observations – for instance, the ground-truthing of rainfall estimates obtained via the various remote-sensing techniques.

In addition to the measurement of surface parameters, important upper-air variables for monitoring climate change are temperature and humidity, especially with respect to their strong contribution to the enhanced greenhouse effect. Upper level (particularly stratospheric) winds and measurements of atmospheric constituents and trace gases are also very important. As all the data need to be accurate and unbiased, care must be taken to ensure that metadata are available to allow radiosonde and satellite-based temperature and humidity profiles to be determined to known quality with established error bars. The GCOS/AOPC Panel has recently (2011) recommended that space agencies do everything they can to prolong the lifetime and exploitation of currently flying instruments on certain satellite missions.

Proportionally the greatest impacts on human society, ecosystems, etc is where extreme events overwhelm systems' coping ability. Accordingly, data on extreme events are essential. Important phenomena to be monitored include tropical and mid-latitude cyclones, high wind events, storm surges, heat waves, cold spells, frost, hail, blizzards, floods and droughts. For most purposes daily data are needed and for some parameters, hourly data. In some circumstances, however, for example stormwater modelling in urban settings, minute-by-minute data are required. In addition, the social, economic and environmental impacts of extreme events, as with longer-term anomalies, need to be recorded as systematically and objectively as possible. From an observational viewpoint, instruments need to be fit for purpose to measure extremes; it is recommended that higher-capacity raingauges, for instance, be utilised in areas prone to heavy rainfall (to minimise losses due to overflowing raingauges), that anemometers in cyclone-prone locations are robust enough to measure extreme wind gusts without being destroyed¹⁰, and that instrumentation in very cold locations is able to cope.

Even the longest of instrumental records are not long enough to adequately capture climate and its variability over long time scales. **Paleoclimate data** (indirect information from tree rings, ice cores, corals, historical documents, etc.) allow the instrumental record to be placed in a much longer context. Isotopic concentration of precipitation data (²H, ¹⁶O, ¹⁸O) is very important in paleoclimatological studies to assess ice cores and historical water. IAEA's networks; GNIP, GNIR and MIBA are good supporters for Paleoclimate and they needs to be improved. They are particularly important for assessing the uniqueness of recent trends, together with climate model results and estimates of past forcing. The consistency of paleoclimate data, and their interpretation in terms of instrumental measurements, requires ongoing research.

Some related Data Management and support processes.

The secure archival of data in custom-built climate data management systems (CDMS) is an essential underpinning of all climate services and activities, as they facilitate data collection, quality control and monitoring, archival, and interactive services. For this reason, the Commission for Climatology has placed emphasis on the development and implementation of CDMS in all countries. Quality assurance is a vital component for ensuring climate data are fit for purpose.

¹⁰ A recent example (Feb 2011) was the destruction of the anemometer at Willis Island (Aust), at a relatively early stage of the onset of Category 5 Cyclone *Yasi*. A robust anemometer would have permitted extremely valuable data on this powerful cyclone to be collected and analysed.

Efforts should be made to ensure that climate data - at least for the Essential Climate Variables – are subject to suitable quality control processes, and that the results of these processes are fed back to observation managers to ensure improvement in the quality of the incoming data. Geographical Information Systems (GIS) are also important tools for disseminating and visualising data-related products and services to end-users. To the extent that these systems are not directly related to observational systems, they will not be discussed further here; suffice it to say, however, that careful consideration is needed when planning end-to-end data flows from point of observation to ingest, archival, quality control of, and ultimately access to, climate data. Observational managers need to be involved in such plans.

It is also important that regular calibration and maintenance of meteorological instruments is carried out, including standardizing and comparing instruments, and ensuring staff conducting these activities are adequately trained and comply with well-established procedures such as frequency of inspection.

Up-to-date metadata on these and other observational issues are essential for ensuring the reliability and fitness for purpose of climate records, for assessing the effects of local land-use changes, and for applying necessary homogeneity corrections. Current and historical metadata should be, to the extent possible, stored in electronic form and made readily accessible. All surface variables need to be monitored to the required accuracy and recorded using consistent statistical methods (for example, standard wind speed averaging periods) (see CEOS/WMO database for a list of all required variables and monitoring accuracy). Major efforts must be made to ensure the long-term viability of observational networks (as above), and that data losses are kept to an absolute minimum. This poses particular challenges in developing countries, where implementation of automated observing systems is increasing rapidly as a proportion of the overall observing network. Principally, the needs of the climate program must be paramount when automating networks. This requires that the installation, communications, and most importantly, the ongoing maintenance of stations, be resourced sustainably. It also requires ongoing dialogue between NMHS climate scientists and observation managers, in the areas of network planning, end to end quality assurance processes, and requirements analysis.

All NMHSs need to be cognisant of the need to secure their raw data against loss, and therefore a data rescue program is required in all countries. Data rescue is the process of preserving those data at risk of loss due to deterioration of the medium on which the data are stored (paper, microfilm, etc), which can occur under certain climate conditions such as high humidity, or can be related to failure to modernize or secure storage technologies. Rescue of data in paper-based or obsolete electronic formats, and the digitization of current and past data, into CDMS-compatible form for easy access are vital activities. Data Rescue is carried out under well-established initiatives such as MEDARE and ACRE (which, during CCI XV, were appreciated by Members), and has also been supported by certain bilateral or multilateral projects sponsored by, e.g., Aid Agencies in developed countries.

Automation of observations needs to be carefully managed, to ensure that data homogeneity and continuity are not adversely affected. It is recommended that AWS systems for climate purposes conform with minimum standards of siting, precision, maintenance, data back-up, and robustness of communication with the NMHS climate database (the CCI is developing such a set of guidelines). Noting that manual and automated observing stations have complementary strengths and weaknesses for climate, efforts should continue to ensure network planners take account of these synergies, and address issues that may impact on the homogeneity and completeness of the climate record.

Significant changes to observational practices need an adequate change management process. Overlap studies have already been mentioned, and it is desirable for some assessment of impacts on climate products and services to be conducted prior to the change. The closure of some stations or networks may require the development or acquisition of replacement data-types; for instance, the closure of airport radiosonde stations can in principle be supplemented by collection of aircraft-sensed observations such as AMDARS or vertical profilers. Again, a careful

change management process is required to ensure any negative impacts on data quality are minimised.

4. SUMMARY AND CONCLUDING REMARKS

Established networks largely meet traditional needs for climate data; however substantial vulnerabilities exist, particularly in developing and least-developed countries. These vulnerabilities are often centred around resources (including funding).

The costs of collecting climate-quality data, often poorly met through government funding, have contributed to declines in observing networks and capabilities around the world. Apart from the loss of, or reduction of, many data types, such cost issues can have other unfortunate effects such as inadequately managed automation, and to charging for data. The former can lead to data loss and inhomogeneities; the latter can lead to restricted availability of data for studies and applications, and can deter users from working with NMHSs on their climate activities. Training and skills issues, too, and the cost of consumables for, e.g., the high quality GUAN network, can also affect observational quality and quantity. Attention is needed to ensure that these vulnerabilities are addressed, including resource mobilization to support key climate monitoring stations.

Since the 1990s, some progress has been made in halting the degradation of observing networks. New observing systems have been established, but a number of past concerns remain (e.g. filling gaps in coverage). The introduction of automated surface networks has resulted in improved temporal frequency of observations, but this is often at the expense of manually observed parameters such as cloud cover and snowfall. Improved communications and some training are required to ensure that CLIMAT messages are properly and routinely sent and received. CDMSs potentially provide a means of automating CLIMAT message generation

A critical element of a country's climate variability and change monitoring program is its GSN and GUAN observations, which represent a few (spatially), but very high quality datasets. The GSN and GUAN networks need to be augmented by much denser national and regional networks that truly reflect climate variability and change over areas representing different climate zones, vulnerable areas (e.g. glaciers, coastal areas), and socio-economically important areas. CCI and GCOS have agreed that Reference Basic Climate Networks (RBCNs), which provide that improved spatial resolution, should comprise part of the GCOS monitoring effort. These represent an example of tiered networks, in which a level of stringency in observational practice is invested in these high quality monitoring stations that is not necessarily required for stations servicing other needs. Homogeneity and completeness of records are vital for all climate change studies, and are particularly crucial for the RBCNs; more generally, long-term, calibrated, and as far as possible uninterrupted observations comprise the best foundation for most climate-related applications and services.

Programs on data rescue should continue to find, secure and where resources permit, digitise all available historical records, with priority going to those stations identified as climatically significant, as in the previous point.

Manual and automated observing stations each have strengths and weaknesses in regard to observations for climate purposes. Since it is essential that observations used for climate studies meet certain standards of quality and continuity, efforts should continue to ensure network planners address issues that may impact on the homogeneity and completeness of the climate record. Recent findings of WMO's Commission for Instruments and Methods of Observation (CIMO), for example, show that there can be considerable differences in observed values, depending on the instrument and method used, which may have a direct impact on the consistency of the climate records. A proper change management process, with climate experts as major stakeholders, needs to be carried out whenever significant changes are planned (or have already been implemented without impact studies) for observing systems, processes, or networks. The information from bodies such as CIMO must also be responded to in an appropriate manner.

Satellite data may greatly assist in providing high-resolution data in areas where *in situ* observations are sparse or absent. The climate program should collaborate with projects and initiatives focussing on the integration of different observing systems, and to explore the potential of remote-sensing techniques for representing climatically-significant variables. The issue of ground-truthing, an important facet of integrating remotely sensed observations to conventionally observed data, is very important.

Many established observing systems have yet to implement the GCOS Climate Monitoring Principles (Appendix 2). There is a need to ensure that observation program managers and network planners consult closely with climate programs to ensure their actions do not adversely affect the climate record. This should be done at the international level through appropriate consultation between WMO Program areas, and at the individual NMHS level.

Appendix 1: Organisational context of the CCI

The Commission for Climatology (CCI) is one of eight Technical Commissions of the World Meteorological Organization. It is supported by the World Climate Programme (WCP) and its sub-programmes. With respect to applications of climate, the **World Climate Applications and Services Programme (WCASP)** and its **Climate Information and Prediction Services (CLIPS)** project are core elements of WMO's approach to climate services. The **WCASP** fosters the effective application of climate knowledge and information for the benefit of society and the provision of climate services, including the prediction of significant climate variations both natural and as a result of human activity. The **CLIPS** project deals with the implementation of climate services around the globe. It strives to take advantage of current data bases, increasing climate knowledge and improving prediction capabilities to limit the negative impacts of climate variability and to enhance planning activities based on the developing capacity of climate science. Climate data aspects are represented by the **World Climate Data and Monitoring Program (WDCMP)**, which covers climate observation networks and systems, climate data management and exchange, climate datasets, metadata and indices, and climate watch and alert systems. The CCI has retained strong links with a range of other technical commissions, through involvement in Expert Teams and joint activities, as well as through Rapporteur activities, the latter for instance, linking CCI with the Commission for Hydrology and the Commission for Agricultural Meteorology.

The adoption and implementation of the Global Framework for Climate Services (GFCS) has led to a refocussing of the activities of CCI to align with the four technical pillars of GFCS, namely (1) User Interface Programme (UIP); (2) Climate Services Information System (CSIS); (3) Research and modelling; and (4) Observations and monitoring. It is envisaged that CLIPS will cease as a project by 2015; its achievements are at the root of the GFCS, and progress achieved under WCASP and CLIPS will be furthered within the CSIS and the UIP components of the GFCS.

The first version of this Statement of Guidance was drafted in 2009, and revised in March 2010, by Dr Raino Heino. At the Fifteenth session of the Commission (CCI-XV) (Antalya, Turkey, February 2010), CCI adopted a vision to provide world leadership in, expertise in, and international cooperation in, climatology. Its mission is to stimulate, lead, implement, assess and coordinate international activities within WMO under the World Climate Programme (WCP) and the GFCS, aimed at obtaining and applying climate information and knowledge in support of sustainable socio-economic development, environmental protection, and preservation of life. To better accomplish this, CCI reorganized itself along four thematic lines, now called Open Panels of CCI Experts, or OPACEs. These include OPACE I (Climate Data Management); OPACE II (Climate Monitoring and Assessment); OPACE III (Climate Products and Services and their Delivery Mechanisms); and OPACE IV (Climate Information for Adaptation and Risk Management). OPACE 1 is most closely aligned with the standards and requirements for observing systems in support of climate services. OPACE 1 interacts with each of the other OPACEs, including OPACE IV, which is focussed on developing climate information, products and services, and which made a major contribution to this version of the SoG. The CCI OPACEs also collaborate closely with relevant Technical commissions such as CBS, CHy, CAgM, JCOMM and CIMO, and with World Climate Programme entities including the new World Climate Services Programme (WCSP) and the co-sponsored Programmes GCOS and WCRP (by decision in 2011 of the sixteenth World Meteorological Congress).

Appendix 2: GCOS Climate Monitoring Principles

Effective monitoring systems for climate should adhere to the following principles. (The ten basic principles were adopted by the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) through decision 5/CP.5 at COP-5 in November 1999. This complete set of principles was adopted by the Congress of the World Meteorological Organization (WMO) through Resolution 9 (Cg-XIV) in May 2003; agreed by the Committee on Earth Observation Satellites (CEOS) at its 17th Plenary in November 2003; and adopted by COP through decision 11/CP.9 at COP-9 in December 2003.)

1. The impact of new systems or changes to existing systems should be assessed prior to implementation.
2. A suitable period of overlap for new and old observing systems is required.
3. The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (i.e., metadata) should be documented and treated with the same care as the data themselves.
4. The quality and homogeneity of data should be regularly assessed as a part of routine operations.
5. Consideration of the needs for environmental and climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional and global observing priorities.
6. Operation of historically-uninterrupted stations and observing systems should be maintained.
7. High priority for additional observations should be focused on data-poor regions, poorly observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution.
8. Long-term requirements, including appropriate sampling frequencies, should be specified to network designers, operators and instrument engineers at the outset of system design and implementation.
9. The conversion of research observing systems to long-term operations in a carefully-planned manner should be promoted.
10. Data management systems that facilitate access, use and interpretation of data and products should be included as essential elements of climate monitoring systems.

Furthermore, operators of satellite systems for monitoring climate need to:

- (a) Take steps to make radiance calibration, calibration-monitoring and satellite-to-satellite cross-calibration of the full operational constellation a part of the operational satellite system; and
- (b) Take steps to sample the Earth system in such a way that climate-relevant (diurnal, seasonal, and long-term inter-annual) changes can be resolved.

Thus satellite systems for climate monitoring should adhere to the following specific principles:

11. Constant sampling within the diurnal cycle (minimizing the effects of orbital decay and orbit drift) should be maintained.

12. A suitable period of overlap for new and old satellite systems should be ensured for a period adequate to determine inter-satellite biases and maintain the homogeneity and consistency of time-series observations.
 13. Continuity of satellite measurements (i.e. elimination of gaps in the long-term record) through appropriate launch and orbital strategies should be ensured.
 14. Rigorous pre-launch instrument characterization and calibration, including radiance confirmation against an international radiance scale provided by a national metrology institute, should be ensured.
 15. On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored.
 16. Operational production of priority climate products should be sustained and peer-reviewed new products should be introduced as appropriate.
 17. Data systems needed to facilitate user access to climate products, metadata and raw data, including key data for delayed-mode analysis, should be established and maintained.
 18. Use of functioning baseline instruments that meet the calibration and stability requirements stated above should be maintained for as long as possible, even when these exist on decommissioned satellites.
 19. Complementary *in situ* baseline observations for satellite measurements should be maintained through appropriate activities and cooperation.
 20. Random errors and time-dependent biases in satellite observations and derived products should be identified.
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Appendix 3. Some non-climatic factors increasing food insecurity.

Changing Land Use

Population pressure and political interests in land ownership in some African countries has led to fragmentation of land holdings into small and inadequate land for household food production. This has increased household food insecurity.

Population growth has increased demand for food requirements. This has led to opening up of Arid and Semi Arid Land (ASAL) for cultivation and settlement without appropriate farming and soil and water conservation techniques and practices. Combined with cultivation on steep slopes, riverbanks and clearing of forests, these land use practices have left soils vulnerable to slightest floods and erosion.

Erosion of Coping Strategies

Deterioration of environment and loss of biodiversity have reduced availability of wild foods. Establishment of game parks and reserves in some countries has not only protected game that communities would fall back to but along with other developments has alienated grazing reserves from the nomadic pastoralists, leaving them vulnerable to droughts.

Lack of Drought Preparedness at Household Level

Climate and weather information for drought preparedness does not reach many farmers and is still received with scepticism. Hence such information is not effectively used at household level. Forecasts, including seasonal outlooks, are not livelihood zone specific and are not used in decision-making at farm level. As such most households are usually not prepared for droughts.
