New Technologies and Observation Instrumentation Innovations: From Urban to Global Scales

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ABSTRACT

This is the description of the session and needs to be amended after wwosc considering the salient points from the session (which will be included in more detail in the paper).

Substantial progress has been made in numerical weather prediction (NWP) through the advancements in data assimilation and the assimilation of better and novel observations of many parameters and on various scales. This session of the World Weather Open Science Conference takes stock of the advances that have been made and emphasizes on all aspects of observation innovations ranging from in-situ sensors to remote sensing from space. Special emphasis is on the integration of measurements into a coherent picture thus covering a better depiction and understanding of atmospheric phenomena on different scales. Sensor networks like weather radar, GNSS, lightning, ceilometers or other emerging instruments are expected to play an increasingly important role in future integrated observing systems. As the satellite observing system is crucial to guarantee the operational and routine spatial and temporal coverage, it is essential to continuously improve the utilization of satellite observations, to enhance the coordination of satellite observations in complementary manner, and to strive for future innovations addressing current gaps in the satellite observing system.

1. INTRODUCTION (max 300 words)

This white paper was prepared by contributors to the session on ‘New Technologies and Observation Instrumentation Innovations: From Urban to Global Scales’ at the WWRP Open Science Symposium held in Montreal in August 2014. It provides some high-level background and most importantly reflects the salient messages from the oral and poster sessions.

The role of satellites for numerical weather prediction and also for climate monitoring has enormously increased over the last two decades. Nowadays it has been established that satellite data are the most important ingredient to today’s operational numerical weather forecast models, however it is important to recall that in-situ data (e.g. from radiosondes and aircraft) and ground-based remote sensing data remain a an important pillar for numerical weather prediction (NWP), mainly because of better spatial, especially vertical,

resolution and also because most of the space-based remotely sensed data are still prone to bias errors. There are however activities such as the Global Space-based Intercalibration System (GSICS) (Goldberg et al., 2011) which have made substantial progress toward accurate satellite radiance observations. As mainly dictated by the relatively large requirements on technology and on financial planning, satellite systems have innovation cycles of a decade or more, which is especially true for the operational satellite systems. Although this might be considered slow it has advantages too, notably that operational services are continuous over longer periods and that the user community has time to develop the optimum utilisation of the data over time. The latter is a decisive element when it comes to the definition of a new satellite system.
Ground-based techniques can respond to new technologies on a much shorter time scale paving the way for future space mission. This is particularly true for advancements in automatization, miniaturization and communication that allows new types of sensor networks to emerge.

In this paper we will concentrate on the novel aspects of future observing systems with focus on the future challenges for NWP developing towards even finer spatial resolution to improve the representation of the atmospheric boundary layer and convective precipitation. However, it needs to be noted that for the operational systems innovations are often incremental on top of continuity because operational systems have the necessity to continue beneficial established services.

2. OBSERVATIONS

2.1 In-situ and ground-based remote sensing observations

Observations at surface synoptic stations and upper air soundings by radiosondes have long been the backbone of the meteorological observation network. Both the cost of the of these person intensive measurements and the need for better capture convective processes with high temporal and spatial coverage have pushed forward new sensor technologies that have now reached different degrees of maturity. While some of the techniques presented below are already assimilated into NWP for others challenges lie in the setup and operation of unattended all-weather observations and harmonized quality assurance to make them usable for NWP and eventually climate monitoring.

2.1.1 Insitu observations

Sensor miniaturization and integration has lead to the fact that meteorological parameters like temperature and pressure are measured by many millions of devices, e.g. watches, smartphones. However, how such frequent but not standardized (calibrated) sensors can be exploited to improve NWP is not clear yet. Moore (PS168.04) make use of 6,000 individual surface pressure measurements from a crowdsourced archive of surface pressure data collected by individuals using the barometer installed on all Android smartphones and the PressureNet App to learn more the July 2013 Toronto flooding event. Further approaches investigate whether flexible and biodegradable electronic components can be deployed in large ensemble with each of the components weighing about 1 gram (Manobianco PS105.03) to capture the 3D structure of the atmosphere. The integration of new and standard technologies to offers new possibilities not only for NWP but also for climate monitoring (Bergeron PS105.04 - The Quebec climate monitoring program1996-2012) but requires new challenges in terms of data homogenization.

Almost all radiosoundings today exploit GPS for determining horizontal wind. Sondes have become smaller and flexible but the provision of high quality harmonized data sets including not only sondes launched by meteorological services is ongoing research topic, e.g. providing high vertical resolution and correction of upper troposphere humidity. An example for such an effort is the database of more than 22,000 GPS drop sondes (Wang PS105.02) that were gathered from NOAA hurricane flights into 125 tropical storms. With the increasing use of unmanned aerial vehicles (UAV) deployment of various in-situ, remote sensing and also drop sondes offers new exiting opportunities for sounding.

The correct representation of surface exchange processes becomes more and more important in NWP, however, the use of in-situ soil moisture networks (PS127.04 – Howard) that are increasingly set up in particular in the hydrolocical community for meteorological applications is still in its early stages.

2.1.2 Ground-based remote sensing

Various remote sensing instruments offer inexpensive, unmanned ground based observation possibilities for continuous profiling of winds, humidity, temperature, clouds and aerosol properties:

- Ceilometer networks that are also deployed by meteorological services for visibility and cloud base also give aerosol backscatter profiles that can be used for operational boundary layer monitoring (Hirsikko PS127.02).
- Doppler wind lidars are currently less frequent than ceilometer but offer a more direct signal of the mixing state together with the horizontal wind vector but are limited to the lower (aerosol rich) part of the atmosphere. In recent years their usefulness for wind energy applications leads to a rapid increasing in the number of operating systems making them a candidate for future networks.
- Radar Wind profilers can cover the full troposphere and have a much higher degree of maturity than Doppler lidar. Networks on both sides of the Atlantic, e.g. southern Canada (Taylor et al, PS116.01), CWINDE (Co-ordinated wind profiler networkin Europe) Lehmann PS127.03 have already been established and data from several stations are already assimilated into NWP models.
- Microwave Radiometers can profile water vapor and temperature as well as to derive cloud liquid water path. More than 100 of them are organized in the voluntary MWRnet (An International Network of Ground-based Microwave Radiometers; -PS160.0 Crewell) that develops joint quality assurance procedures and has supported first attempts to assimilate them into NWP.. Further they are used for climate studies and NWP evaluation (Cossu SCI-POS1089).

Experimental studies also explore the use of volume scanning microwave radiometry for convection forecasting (PS160.02 Fabry).

- Infrared spectrometer are superior to microwave radiometer in terms of vertical resolution in the retrieved temperature and humidity profiles but limited to cloud free scences. Ideas for a ground-based observing network, wherein ground-based infrared spectrometers serve as the core instruments at each station are currently elaborated (PS127.0 Turner).

- Water vapor lidar, i.e. Raman and differential absorption lidar (DIAL) allow the determination of high vertical resolution profiles under clear sky conditions. Though they are currently rather complex in terms of operation and cost efforts research to develop low-cost versions is ongoing (PS116.03 Spuler)
- Polarimetric Doppler weather radar are becoming a standard at the ground and are also deployed on aircraft (PS160.03 Lee). Phased array radar (PAR) techniques that instead of mechanical make use of electronic scanning offer an exciting possibility for much faster and flexible scanning of precipitation but also clear-air convection.
- Lightning networks that can observe CG (cloud-ground lightning) and CC (Cloud-Cloud lightning) are increasingly used to investigate the evolution of convective cells structures, lightning activity and electrical vertical structure of heavy rainfall cells (PS168.03 Kanghui).

It is important to note that even with the various instrument approaches outlined above some some outstanding issues such as a true reference turbulence observation 'away from the surface' remains (PS105.01 Rotach).

Each of the instruments only provides limited information on the atmospherics state. Data assimilation into NWP models involving forward operators to convert model variables into the measured quantities provides an efficient mean to exploit non-standard measurement. Another possibility are synergetic retrieval algorithms that combine different remote sensing and/or in-situ measurements to geophysical quantities, c.f. (SCI-PS116.02 Barrera Verdejo; POT1094 Saeed).

In order to demonstrate the usefulness of the different instruments for NWP prototype networks have been setup for different focus points and limited areas, e.g., the Front Range Observational Network Testbed (FRONT) (PS168.02 Hubbert). For Europe the COST action ES0702 aims to specify an optimum European network of inexpensive, unmanned ground based profiling stations, which can provide continuous profiles of winds, humidity, temperature, clouds and aerosol properties with a view on the requirements and tools for data assimilation, e.g. a version of the radiative transfer operator RTTOVS for uplooking geometry.

2.2 Space-based observations

Figure 1 provides a summary of the current Global Space-based Observing System (ref. WMO Space Programme Office) as coordinated by WMO and the Coordination Group for Meteorological Satellites (CGMS) and support from CEOS.

The most important satellite for global NWP and climate observations are from Low-Earth Orbit satellites (EO), either from operational or from R&D missions. They provide essential assuring today's quality of global numerical weather prediction. The WMO baseline for a core LEO constellation is to be deployed over three sun-synchronous orbits with orbital planes around 9:30, 13:30, and around 17:30 Equatorial Crossing Time (ECT). This would ensure a nearly even sampling in time of the atmosphere thus avoiding temporal gap which would be especially severe around dawn and dusk. It would also provide a reasonable observation of diurnal cycles from low-earth orbit although this is better done with geostationary satellites.

The constellation of operational meteorological geostationary satellites remains the backbone of permanent and near-global monitoring of the weather in low and mid-latitudes and provides unique information for Nowcasting and short-range weather forecasting. The latter aspect and potential is likely to emerge evne more with the new generations of geostationary satellites that will gradually be launched by different space agencies over the next five years. Advanced imagery with better spatial (2km or better) and temporal resolution (10 minutes or better) will be avalaible then with the advent of Himawari 8/9 from JMA, the GOES-R series from NOAA, the FY-4 series from CMA and Meteosat Third Generation (MTG) from EUMETSAT and new generations from India (IMD and ISRO) and Russia (Roshydromet). Those scheduled launches do go a long way toward the new vision of WMO. The enhanced commonality/similarity of instruments should pave the way to enhanced globally coordinated research and the development of improved applications.
A summary of technical aspects of the realisation of the WMO vision 2025 includes two main aspects: i) an upgrade of both the geostationary and polar operational satellite systems in terms of coverage and ii) an upgrade of instruments that also invokes more commonality in the instrumentation of each satellite. Specifically that means
(I (js) need to work on this part after the conference):

a) *Improved coverage with geo imagers; enhanced commonality of future imagers covering the geostationary ring with 16 channels (most of the area) and very similar spectral characteristics thus enhanced commonality in world-wide research and utilisation*

b) *Improved coordination of orbits for polar satellites. (This is being addressed by Peng Zhang as keynote speaker who will certainly report on FY-3 in an early-morning orbit)*

c) *Beginning of a constellation of new instruments in geo orbit, i.e. lightning imagers (*Goodman et al. PS168.01) *and hyper-spectral sounders (I will address this in my (j schmetz) talk as well as the new 16 channel imagers).*

d) More common key instrumentation in polar orbits, e.g. GNSS soundings, hyperspectral sounders, micro-wave sounders and imagers

e) It may be worth to mention the potential future lack of a limb sounder (ref. ....)

A novel element in a space-based are observations from a highly elliptical orbit providing improved temporal coverage of high latitudes *(refer to presentation by L. Garand)*

An important step toward increased usefulness of the satellite data are improvements to calibration. The established Global Space-based Intercalibration System (GSICS) (Goldberg et al. 2011) provides a unique framework to put different satellite observations into an observing system where the observations are mutually consistent. If those measurements could be traced to an absolute standard the need for bias-correction by NWP systems may continue however that need would solely emerge from the NWP system as such and not anymore because satellite data have a bias. The realisation of this objective within GSICS would is entail unprecedented opportunities for the evaluation of models and their physics.

Yunck-PS116.04: CICERO (Community Initiative for Continuous Earth Remote Observation) is a grassroots effort to deploy a cellular space-based observing system to acquire global weather, climate and space environmental data from low Earth orbit at extremely low cost

Blanchet PS160.04: FARIr satellite

Goodman: PS168.01 - The GOES-R Geostationary Lightning Mapper (GLM) and the Global Observing
System for total lightning

4. CONCLUSION

A conclusion with no more than 300 words.

Including aspects of synergy between ground-based, airborne and satellite based

systems..

To be added after inputs from OSC.

Acknowledgements

References

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Tables and Figures

Figure 1: Maps of exemplary ground-based networks a) CWINDE network b) European lidar and ceilometer network and c) MWRnet from COST EG-CLIMET final report

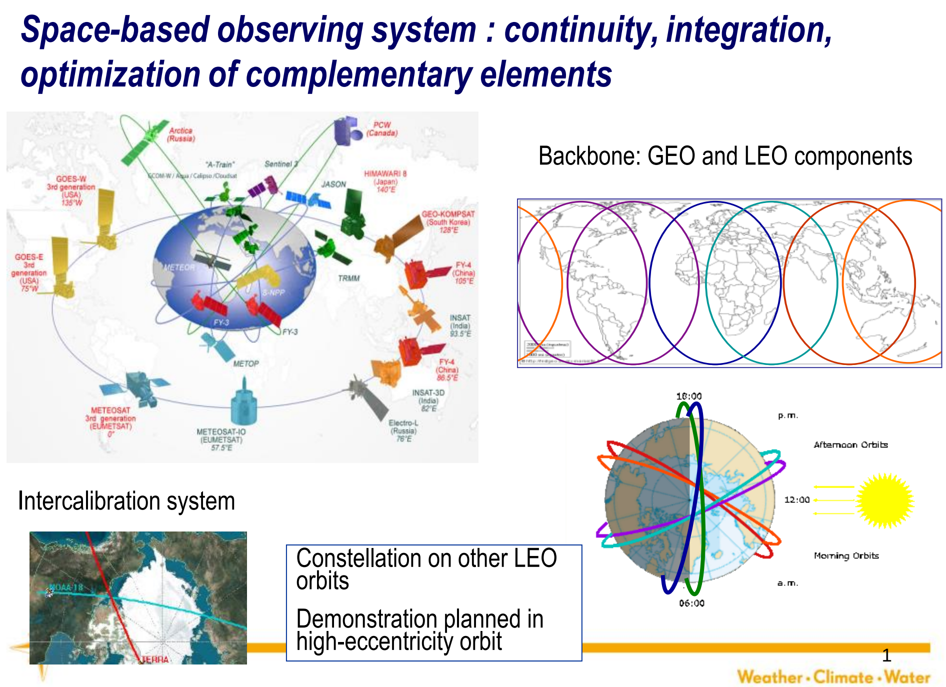

Figure 2: Sketch of the space-based global observing system for both geostationary and polar orbiting operational satellites. The insert also alludes to GSICS (Goldberg et al., 2011) (from WMO Space Programme) (... more detailed description once text is final)