Forthcoming changes in the Global Satellite Observing Systems

Mitchell D. Goldberg

NOAA/NESDIS/JPSS
Mitch.Goldberg@noaa.gov

ABSTRACT
This paper provides an overview of the key observations used for numerical weather prediction (NWP) and the plans of operational and research space agencies to sustain these observations. Real-time access and low latency are critical for numerical weather predictions (NWP), and not all missions provide this access. Generally if all agencies had real-time free and open access the health of observing system is quite good, with the exception of radio-occultation.

1 Introduction

This paper provides an overview of expected changes in the global observing systems, with a focus on weather forecasting. It builds upon the findings of the WIGOS 5th workshop of the impact of various observing systems on numerical weather prediction, noted as the Sedona Report, the WMO Observing Systems Capability Analysis and Review (OSCAR) database which includes an inventory of all past, present and planned satellite missions out to 2030, and the report by Joo et al. (2013) which discusses the impact of various satellite data to reducing forecast errors. The critical data for numerical weather prediction (NWP)were found to be the following:

a) Hyperspectral Infrared Sounders (HSIRS)
b) Microwave Atmosphere Sounders (MWS)
c) Atmospheric Motion Vector (AMV) winds
d) Ocean surface wind Scatterometers (SCAT)
e) GPS Radio Occultation (GPSRO)
f) Microwave Imagers (MWI)
g) Visible and Infrared Surface Imaging (VISI)

MWI and VISI provide critical boundary condition information For example, MWI provides information on ice/snow, surface temperatures, soil moisture, snow water equivalent, total precipitable water, total water content and precipitation, wind speed, sea surface temperature, while VISI provides land/sea/ice surface temperature, vegetation fraction/greenness, snow/ice cover and surface emissivity/albedo.

1.1 Sedona Report

The 5th WMO workshop on the impact of various observing systems on numerical weather prediction (NWP) was held on 22–25 May 2012 in Sedona, Arizona (United States). Some of the key findings of the report are:

- Observations contributing to the largest reduction of forecast errors are those observations with vertical information (temperature, water vapour).
- The single instrument with the largest impact is hyperspectral infrared (IR).
- Microwave dominates because of the number of satellites and ability to view thru low water content clouds.
- There is now no single, dominating satellite sensor.
- GPSRO shows good impact, and largest impact per observation.
- Atmospheric Motion Vector Winds and Scatterometers are single level data and have modest impacts.
- Concerns about the declining number of observations into the future – mostly due to the replacement of 2-year life satellites with 7-year life(e.g. NOAA-15 vs. JPSS-1) and due to de-orbiting requirements to reduce space debris.
- Concerns about decline of GPSRO with COSMIC end of life.
- Depending on the future plans and implementations of satellite agencies, a single sensor failure may begin to have larger ripples in impacting forecast skill.
- High quality data is critical.
- Open and free access of data in near real-time is critical.

1.2 WMOObserving Systems Capability Analysis and Review (OSCAR)

OSCAR (www.wmo-sat.info/oscar) is a resource developed by WMO in support of Earth Observation applications, studies and global coordination. It contains quantitative user-defined requirements for observation of physical variables in application areas of WMO (i.e. related to weather, water and climate). OSCAR also provides detailed information on all earth observation satellites and instruments (past, current and planned), and expert analyses of space-based capabilities.

2 Forthcoming changes

2.1 Hyperspectral infrared and microwave sounders

Hyperspectral infrared and microwave sounders are currently on NOAA, NASA, and EUMETSAT satellites. Both types of sounders have the largest impact of reducing forecast errors. WMO requirements call for a three-orbit constellation represented by the early morning, mid-morning, and early afternoon orbits to provide full global coverage needed every six hours by NWP centres. However it should be noted that real-time access and low latency are also requirements. The agencies that have demonstrated such service for decades are EUMETSAT and NOAA. The community has noted the improvement in access from CMA.

- Afternoon orbit
    - NOAA (13:30) – SNPP (2011), JPSS-1 (2017), JPSS-2 (2021)
    - CMA (14:00) – FY3D (2015), FY3E (2020)
    - Russia (15:30) – Meteor-M N2-1 (2015–2020), N2-3 (2019–2024), N2-5 (2021–2026)

- Mid-morning orbit
  - EUMETSAT (9:30) – Metop-B (2012–2018), -C (2018–2024), -Metop-SG-A1(2021–2028), A2(2028–2035), A3(2035–2042)
  - CMA (10:00) – FY3C (2013–2018)
  - Russia (9:30) – Meteor-M N2 (2014-2019), N2-2 (2016-2021), N2-4 (2020-2025)
- Early morning orbit
  - CMA (6:00) – FY3E(2018–2023), -FY3G (2022–2027),
  - US DoD (5:30) (Microwave sounder only) F19(2014–2020), F20 – unfunded
- Hyperspectral IR sounder – Geostationary
  - EUMETSAT MTG-S1 (2021–2029), MTG-S2 (2029–2037)
  - CMA FY-4A (2016–2022) …FY-4G (2033–2040)West (86.5)and East (105)

2.2 Atmospheric Motion Vectors (AMVs)

The constellation of geostationary satellites for AMVs is very healthy. Starting in 2015, many geostationary imagers will have more than 14 channels with much higher temporal refresh. So we can expect improved accuracy and temporal sampling and spatial resolution. KMA, JMA, NOAA will all have ABI-like imagers. EUMETSAT, CMA and Russia will have their number of channels increase from 10 to about 20 in the 2020s. India will continue to have channels similar to the current GOES imager. Polar orbiting imagers are in good shape, all have more channels and higher spatial resolution. It should be noted that the NOAA VIIRS has no water vapour channel, and the community is recommending to NOAA to add the water vapour band for future missions.

2.3 Scatterometers

Figure 1 shows the satellite constellation chart for scatterometers.At first glance, the number of agencies contributing to scatterometers appears to be quite adequate.

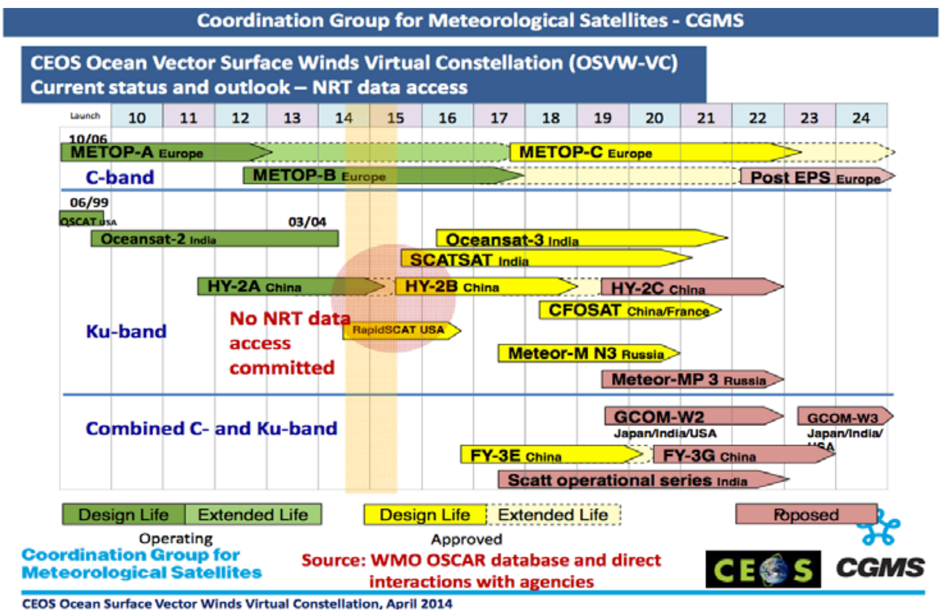

Figure 1: The satellite constellation chart for scatterometers.

However, weather forecasting and nowcasting applications requires good temporal sampling, at least three orbits, ideally equally spaced in time, and near-real-time (NRT)access of the data.As reported by the CEOS Ocean Surface Vector Winds Virtual Constellation to the Coordinated Group for Meteorological Satellites (CGMS) in April 2014:

> “The major concerns of this constellation are the discontinuation of OSCAT operations and the current unavailability of HY-2A winds in NRT. The mission chart suggests numerous missions over the next decade but only a few of these are part of sustained programs.There is a need for long-term international commitment to a sustained global vecor winds constellation, to support short-term extreeme weather forecasting and warning, and for long-term Earth-system forecasting monitoring. As more and more scatterometry missions are planned and approved, a closer look is necessary at the optimum combination of orbit local times, in order to make sure that the overall daily coverage is able to represent faithfully and in an unaliased way the mesoscal convective systems, hurricanes and the diurnal variations and trends of the surface wind field.No scatterometer missions are confirmed within the 0–6hour descending node crossing period,what is the implication for scatterometer spatio-temporal coverage for given locations?What is the implication for the different applications.”

Note that similar figures showing other constellationscan be generated using the OSCAR tool.

2.4 Radio Occultation

The International Radio Occultation Working Group (IROWG) and NWP communities have identified a need for at least 10,000 and preferably 16,000 occultations per day, regularly distributed in time and space. This cannot be achieved before 2020 without both COSMIC-2/FORMOSAT-7 constellations in equatorial and polar orbit. The operational EPS mission will add about 1,300 to the Global Observing System, and the new Chinese mission may further add about 1,300 once its data quality is proven. Arrangements have to be made in order to assure an operational baseline of at least 10,000 to 16,000 occultations after the end of COSMIC-2/FORMOSAT-7.

There are currently about 3,000 occultations available per day in NRT. These are primarily provided by the operational GRAS on Metop-B and Metop-A (which continues to provide data in the same orbit), in total about 1,300 occultations. About 1,700 occultations are provided by non-operational missions: the COSMIC-1/FORMOSAT-3 constellation (about 1,300), GRACE (about 100), and TerraSAR-X (about 180). Truly operational data are expected to be provided by the COSMIC-2/FORMOSAT-7 (equatorial) constellation from 2016 onwards, with at least 4,000 occultations per day, building on COSMIC-1/FORMOSAT-3 heritage, and by EPS-SG satellites from 2021, with at least 2,000 occultations per day. This leaves a strong under representation of mid-latitude and polar observations that will only be solved with the implementation of the COSMIC-2/FORMOSAT-7 (polar) constellation, which however is not fully funded to-date.

2.5 Microwave Imagers – operational conical imagers

The constellation of conical microwave imagers with planned continuity (follow-on missions) include:

- Early morning
  - SSMIS until ~ 2020, likely DoD follow-on.
  - SSMIS include temperature and water vapour soundings.
  - DoD follow-on still pending
  - China: NSOAS,CAST – HY-2C (6:00) -HY2A (2011–2014), HY2B (2016–2019), HY2C (2019–2022), HY-2D (2022–2025)
- Mid-morning
  - EUMETSAT (9:30) –Metop-SG-B1(202–2028), B2 (2028–2035), B3(2035–2042)includes water vapour sounding channels
  - Russia (9:30) – Meteor-M N2 (2014–2019), N2-2 (2016–2021), N2-4 (2020–2025) includes temperature and water vapour sounding channels
  - CMA (10:00) – FY3C (2013–2018)
- Afternoon
  - JAXA(13:30) – GCOM-W1-AMSR2 (2012–2017), GCOM-W2 (2016–2021), GCOM-W3 (2020–2025).
  - CMA (14:00) FY3D (2015), FY3F (2020)
  - Russia (15:30) – Meteor-M N2-1 (2015–2020), N2-3 (2019–2024), N2-5 (2021–2026) includes temperature and water vapour sounding channels

The constellation appears healthy, however there is concern about continuity of JAXA’s GCOM mission past GCOM-W1 in the afternoon orbit, and more information is needed on the continuity of the SSMIS series and its follow-on mission. Real-time data access is critical, and currently this is provided only by SSMIS and AMSR2.Hence there is a concern about continuity of microwave imager data.

2.6 Visible and Infrared Surface Imaging (VISI) from polar satellites

The following mission supports global coverage of key information on land, ocean, cryosphere observations from operational satellites.

- Early morning
  - CMA/(MERSI)(6:00) – FY3E (2018–2023), -FY3G (2022–2027)
- Mid-morning
  - EUMETSAT(AVHRR/SG- METIMAGE) (9:30) – Metop-B (2012–2018), -C (2018–2024), Metop-SG-A1(2021–2028), A2 (2028–2035), A3 (2035–2042)
  - Russia (MSU-MR) (9:30) – Meteor-M N2 (2014–2019), N2-2 (2016–2021), N2-4 (2020–2025)– similar to AVHRR
  - CMA (MERSI) (10:00) – FY3C (2013–2018)

- Afternoon
  - NOAA (VIIRS) (13:30) – SNPP (2011), JPSS-1 (2017), JPSS-2(2022)
  - CMA (MERSI) (14:00) –FY3D (2015), FY3F (2020)
  - Russia (MSU-MR) (15:30) – Meteor-M N2-1 (2015–2020), N2-3 (2019–2024), N2-5 (2021–2026)

2.7 Emerging satellite data

This paper focused on the use of current satellite data types in NWP. However we expect over the next decade that more of the following data types will be assimilated in models.

- Lidar (winds, aerosols, clouds)
- Salinity/Soil Moisture
- Lightning mappers
- Ocean Color
- Atmospheric composition.
- Altimetry

2.8 ESA's Sentinel Mission

ESA's sentinel mission is providing sustained data to the community well into the 2030s.The data needed for operational weather forecasting will be made available in near-real-time by EUMETSAT. The following information is from:
http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Overview4

Each Sentinel mission is based on a constellation of two satellites to fulfill revisit and coverage requirements, providing robust datasets for Copernicus Services. These missions carry a range of technologies, such as radar and multi-spectral imaging instruments for land, ocean and atmospheric monitoring:

- **Sentinel-1** is a polar-orbiting, all-weather, day-and-night radar imaging mission for land and ocean services. The first Sentinel-1 satellite was launched on a Soyuz rocket from Europe's Spaceport in French Guiana on 3 April 2014.
- **Sentinel-2** is a polar-orbiting, multispectral high-resolution imaging mission for land monitoring to provide, for example, imagery of vegetation, soil and water cover, inland waterways and coastal areas. Sentinel-2 will also deliver information for emergency services.
- **Sentinel-3** is a multi-instrument mission to measure sea-surface topography, sea- and land-surface temperature, ocean colour and land colour with high-end accuracy and reliability. The mission will support ocean forecasting systems, as well as environmental and climate monitoring.
- **Sentinel-4** is a payload devoted to atmospheric monitoring that will be embarked upon a Meteosat Third Generation-Sounder (MTG-S) satellite in geostationary orbit.
- **Sentinel-5** is a payload that will monitor the atmosphere from polar orbit aboard a MetOp Second Generation satellite.
- **Sentinel-5 Precursor** satellite mission is being developed to reduce data gaps between Envisat, in particular the Sciamachy instrument, and the launch of Sentinel-5. This mission will be dedicated to atmospheric monitoring.
- **Sentinel-6** carries a radar altimeter to measure global sea-surface height, primarily for operational oceanography and for climate studies.

3 Summary

The polar constellation of hyperspectral IR and microwave soundings are in relatively good shape. EUMETSAT and NOAA will continue to provide sustained observations in the mid-morning and early afternoon orbits for decades. The important contribution by CMA to provide observations in the early morning orbit is well received by the community. Hyperspectral IR will be on EUMETSAT and CMA geostationary satellites. Ideally all geostationary satellites should have hyperspectral infrared sounders as well as microwave sounders. Atmospheric motion vectors are in very good shape. Advanced geostationary imagers will have at least 14 channels. The hyperspectral infrared sounders by EUMETSAT and CMA will improve AMVs by providing better vertical sampling. It is important to advocate the water vapour channels for NOAA VIIRS, since the sample size of AMVs in the polar regions are significantly reduced because only cloud track winds are available.

Scatterometers are generally in poor shape because all missions do not provide real-time access. EUMETSAT will have a follow-on to ASCAT for the mid-morning orbit.HY2 series provides early morning orbit data, but no real time access.CMA is planning for an early morning scatterometer. India's OceanSat2/3 will be in a noon orbit, but no plans by any agency for an early afternoon coverage in order to provide adequate temporal sampling.

GSP-RO is in precarious shape. However, approval for a full COSMIC2 constellation of six equatorial and six high inclination orbits would solve most issues by providing about 16,000 soundings per day. Real-time access is very important.

There are concerns on the constellation of microwave imagers. There is uncertainty to the follow-on to GCOM-W1in the afternoon orbit and SSMIS in the early morning. In the 2020s to 2040s EUMETSAT's second generation MeTOP will provide observations in the mid-morning. CMA plans to have MWIs in the mid-morning and early afternoon, and more information is needed on their plans for the early morning orbit. Note that CMA will have one more mid-morning orbit, and then populate the early morning orbit. There will be a likely US DoD mission in the early morning following SSMIS, but more information is needed. Russia plans to have mid-morning and early afternoon orbits for MWIs. But again it needs to be reiterated that real-time access, similar to services provided by NOAA and EUMETSAT, is required for any new capabilities. Also the quality of the data for agencies adding new capabilities must be demonstrated. Currently NWP centres rely on DoD (SSMIS) and JAXA's GCOM-W. It is important to get a commitment from DoD and JAXA on their plans, since these data have been demonstrated by weather services to be important observations for not only medium range forecasting, but also for assessments and short term forecasting of severe weather events including tropical cyclones.

The constellations of visible and near infrared imagers are in very good shape. Advanced geostationary imagers with more than 14 channels will be common. Polar orbiters from EUMETSAT, NOAA and CMA (mid-morning, early afternoon, early morning, respectively) will provide global coverage. Also Russia plans to have a mid-morning and early afternoon mission, and CMA plans to continue early afternoon orbit observations.

Again, real-time data access to secured data cannot be overstated. Low latency is critical and needs to be achieved by at least two polar ground stations. Direct readout for local applications and to relay data to weather services via the global telecommunication service (GTS) to reduce latency is very important. More study is needed to see which missions actually achieve the latency required by weather forecasting.

References

Joo, S., J. Eyre and R. Marriott, 2013: The Impact of MetOp and Other Satellite Data within the Met Office Global NWP System Using an Adjoint-Based Sensitivity Method. *Mon. Wea. Rev.*, **141**, 3331–3342.