Value of Satellite Data for the Global Framework for Climate Services

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1. Introduction

At the WMO ET-SUP-7 meeting (May 2013), a paper outlining the desirability to develop case studies to demonstrate the value of satellite data for climate services (ET-SUP-7/Doc. 7.2) was discussed. Reference was made to the "Strategy Towards an Architecture for Climate Monitoring From Space" which addresses the desirability of maintaining delivery of satellite-based observations for analysis of the Earth's climate system. A logical view of this architecture describes the information flow and dependencies inherent from the making measurements of relevant quantities from satellites ("sensing") through to the production of climate data records, and their downstream applications amongst various end-users, often for policy and decision making purposes.

The Group on Earth Observations (GEO) societal benefit area (SBA) framework, which considers nine distinct areas (see www.earthobservations.org) provides a useful template for analyzing the state of readiness and usability of these measurements to address a key decision in a specific SBA. As noted in Doc. 7.2, the WMO publication, "Climate ExChange", provides multiple case studies of how collections of space-based observations can inform and enhance the decision making processes of end users. In addition, space and meteorological agencies worldwide have created dedicated programs to improve the uptake of these observations for decision making for both near-term and climatic timescale applications.

This report describes some of existing agency applications programs, further analyzes the case studies presented in "Climate ExChange" as well as from other selected sources, and finally describes efforts to conduct economic analyses of these applications.

2. Space and meteorological agency relevant activities

Providing climate, composition, and other meteorological information derived from space-based observations to non-science end-users is a challenge. The data, often derived from research instruments, is not always contiguous in time, has differing spatial footprints, and may come from multiple instruments. Constructing useable information for end-user needs often requires intercomparing data sets, understanding their uncertainties and limitations, validating measurements against other products, potentially harmonizing (i.e., combining) disparate data sets, and providing the information in useable formats at appropriate latencies required by the decision maker.

During the past 15 years, many research and observational agencies have created programs to demonstrate the usability of space-based observations to end users across the GEO SBAs, including applications relevant to climate services. In this section, a representative sample of these programs is described, together with some relevant highlights of their activities. The outputs from these Programs can provide many case studies and best practices to demonstrate practical examples of the logical view model of the climate architecture.

a. CSA Earth Observation Applications and Utilizations (EOAU)

The Canadian Space Agency has established an Earth Observation Applications and Utilizations division (http://www.asc-csa.gc.ca/eng/observation/applications.asp) that seeks to facilitate Earth observation data access. There are multiple programs within this division; the Earth Observation Application Development Program (EOADP) emphasizes development of applications by the private sector to maximize space-based measurement utilization.

b. ESA

The European Space Agency has multiple programs to facilitate the conversion of basic research and development into an operational services. ESA's Data User Element program addresses institutional users tasked with collecting specific geographic or environmental data, while ESA's Earth Observation Market Development program provides a framework to organize end-to-end service chains capable of leveraging scientific Earth Observation data into commercial tools supplied by end-users (http://www.esa.int/Our_Activities/Observing_the_Earth/Integrating_Earth_Observation_in_your_job).

c. Copernicus (formerly GMES)

Copernicus is the new name for the Global Monitoring for Environment and Security programme (GMES). This initiative is led by the European Commission (EC) in partnership with ESA and the European Environment Agency (EEA). ESA coordinates the delivery of data from space-based assets, while the EEA is responsible for data from airborne and ground sensors. The Space Component is in its pre-operational stage, serving users with satellite data currently available through the Copernicus Contributing Missions at national, European and international levels. Copernicus will become operational after launch of the first Sentinel mission (http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Overview3).

d. Geoscience Australia

Geoscience Australia currently provides Earth observation services, expert advice, and information for decision makers through their National Earth Observation Group. These activities include the provision of decision support information and products to end-users and emergency managers. A study for Geoscience Australia (http://www.crcsi.com.au/43pl/Industry-Development/Industry-Reports/Economics-of-earth-observation) sought to estimate the economic value of space-based Earth observation activities. The study, conducted in 2008, helped inform national space policy for Australia.

e. ISRO Space Applications Center

The Indian Space Research Organisation (ISRO) Space Applications Centre (SAC) focuses on the design of space-borne instruments for ISRO missions and the development and operationalization of applications of space technology for societal benefits. SAC activities involve the full chain of space-based information: from the retrieval of biophysical and geophysical parameters from space borne imaging sensors, assimilation of remote sensing derived parameters, in-process modelling pertaining to interactions within the geosphere-biosphere system and atmosphere to the development of end-user application methodologies (www.sac.gov.in).

f. NASA Applied Sciences Program

The NASA Applied Sciences Program (http://appliedsciences.nasa.gov/) is organized around the 9 GEO societal benefit areas, but focuses, at present, on Disasters, Ecological Forecasting, Health & Air Quality, and Water Resources. The Program seeks to demonstrate the practical benefit of space-based Earth observations through competitive solicitations and some directed programs. The Program's most recent annual report (http://appliedsciences.nasa.gov/pdf/2012AnnualReport_508.pdf) provides case studies demonstrating the use of NASA observations and models (using derived satellite observations and reanalyses) to decision making.

The NASA SERVIR program (http://www.nasa.gov/mission_pages/servir/), a joint venture with the US Agency for International Development, seeks to improve environment management and resilience to climate change by strengthening the capacity of local government and other key stakeholders to integrate Earth observations into decision making. It has established three regional nodes, in Central America, East Africa, and in Nepal to work directly with local stakeholders (governments, academia, and end-users) to improve the uptake of these observations in decision support tools.

g. NOAA RISAs

The US NOAA's Regional Integrated Sciences and Assessments (RISA) program supports research teams that enhance the capacity to prepare for and adapt to climate variability and change. RISA teams work with public and private user communities to, inter alia, advance understanding of policy, planning and management contexts and to innovate products and tools to enhance the use of science in decision making (http://cpo.noaa.gov/ClimatePrograms/ClimateandSocietalInteractions/RISAProgram/AboutRISA.aspx).

h. UK National Center for Earth Observation (NCEO)

The NCEO is a partnership of scientists and institutions in the UK who work to enhance the use of Earth observation data (http://www.nceo.ac.uk/). NCEO researchers form collaborations with business to improve innovation in Earth Observation as well as pushed forward the cutting edge of scientific understanding. NCEO also seeks to ensure that scientific knowledge from Earth observations is translated into benefits for end-users, such as UK government agencies, commerce, and the general public.

3. Case Studies demonstrating the Flow of Space-based Observations to Climate-related Services

Across all of the programs described above, a common challenge is ensuring the sustainability of these projects. Beyond satellite imagery, which is used in numerous applications and which has a large, knowledgeable user base, the application of essential climate variables to address end-user needs frequently requires interpretation and assistance from discipline experts. Non-science end-users usually desire input data in units and formats that are compatible with existing tools and with industry standards. The translation of Earth observation data to these formats can, in many cases, require significant processing by researchers and an ongoing investment to maintain and update these data as necessary, depending on latency requirements of the application (see section b for an example). Since the majority of these projects are intended as demonstrations, sustained funding (often from local sources) is required to maintain the flow of the relevant Earth observations from satellite to decision support system.

a. *Climate Exchange*

"Climate ExChange", published by Tudor Rose in 2012, provides case studies describing the utilization of Earth observations, many from space-based assets, to provide data to models and decision support systems providing climate services to end users. Many of these case studies are derived from activities at operational meteorological agencies that are not described in the above section, thus providing an additional rich source of examples that may be used to validate and improve the climate architecture logical view described earlier. An ET-SUP task team assessed these case studies and identified key attributes of each project, including region, climate service, space-based observation (if relevant), essential climate variable(s) employed, and end user. These tables provide a concise summary of many of the studies described in this book. These examples all contribute to the ongoing development of a Global Framework for Climate Services (GFCS).

Table 1: Health

Title of Case study	**Country/ Region**	**Climate service identified**	**Satellite Component**	**Essential Climate variables addressed**	**Comments**
Climate information services for food & agric. Pg 16	Global	Weather & climate forecasts	Contribution to forecasting	Precipitation	Early disease/pest detection is dependent on accurate forecasts
Informing decision-making in health using seasonal climate outlooks – page 96	Australia, Solomon Islands	Monitoring of floods, droughts, determination of malaria vs ENSO	Contribution to seasonal forecasting	ENSO, temps, precipitation, SSTs	In support of vulnerable sectors in decision-making
The Heat Health warning system– page 100	Germany	Heat waves, weather forecasting, wind speeds	Contribution to temperature detection	Temperature, humidity	Collaboration of climate and health services
Climate implications of atm warming – page 103	India	Monitoring floods and droughts, aerosol monitoring	Contribution to aerosol monitoring, clod cover	Albedo, glacier, snow melting, temperature	Aerosol (black carbon) monitoring
UV radiation network - monitoring and forecasting uv index for health protection – page 107	Chile	Ozone monitoring,	Contribution to ozone/uv monitoring, cloud cover	Air temperature, precipitation	Excessive UV radiation leads to human skin cancer
Climate information in support of the health sector – page 110	Madagascar	Weather monitoring, weather related diseases: malaria, plague, Rift Valley fever	Contribution to seasonal forecasting, tropical cyclone activity	Precipitation, temperature, humidity, evaporation	Climate-sensitive human health

Table 2: Agriculture

Title of Case study	**Country/ Region**	**Climate service identified**	**Satellite Component**	**Essential Climate variables addressed**	**Comments**
Mainstreaming climate information for agriculture activities in Kenya - Page 24	Kenya, Australia-	Seasonal and monthly forecasting	Contribution to seasonal and monthly forecasting	Precipitation, SSTs; ENSO	Crop production
Helping the world's poorest farmers adapt to a changing climate- Page 28	Asian-Pacific,	Seasonal and monthly forecasting	Contribution to seasonal and monthly forecasting	Precipitation, SSTs; ENSO	Crop production
Reducing crop loss – pg 31	Indonesia	Seasonal and monthly forecasting	Contribution to seasonal and monthly forecasting	Precipitation, SSTs;	Crop production
Delivering advisory services – page 35	India	Seasonal and monthly forecasting	Contribution to seasonal and monthly forecasting	Rainfall, temps, humidity, cloudiness	Crop production
Climate services for agriculture – pg42	Guinea Bissau	Flooding, drought, coastal erosion	Contribution to seasonal and monthly forecasting	Precipitation	Maritime and civil protection
Supporting decision making - pg 46	Australia	Flooding,	Contribution to seasonal and monthly forecasting	Precipitation, ENSO, SSTs, Southern oscillation Index (SOI)	Sugar production
Seasonal climate prediction - pg 50	Chile	Droughts, floods, cold waves (frosts), heat waves, severe	Contribution to seasonal and monthly forecasting	Precipitation, ENSO, Temps, MJO, SSTs	Crop and animal production

		thunderstorms, hailstones.			
Climate services and agric – pg 53	The Caribbean	Soil erosion, pests and diseases, land degradation, drought	Monitoring of cyclones and hurricanes	Precipitation, SSTs	Food production and security
Climate outlooks for food security – pg 57	Central America	Extreme weather events	Seasonal climate forecasts	Local and regional weather analyses	Food and nutrition security
Climate infor services… pg 63	Mongolia	drought	Vegetation monitoring	Precipitation, temperatures, SSTs	Livestock rearing
Climate change adaptation methodologies - pg 65	Bay of Bengal	Tropical fish extinction, rising sea level, coastal erosion	Monitoring of cyclones and hurricanes, Contribution to seasonal and monthly forecasting	SSTs, sea level rise	Marine fisheries
Improved livelihoods … in semi-arid tropics … pg 69	India, Thailand, Vietnam, China	Land degradation, drought	Contribution to seasonal and monthly forecasting	Precipitation	Food production and security
Climate change impact .. –pg 72	Indonesia	Indicators of fish abundance, global warming	Monitoring of Greenhouse gases (GHGs)	SSTs, chrolophyll-a, phytoplankton, SSTs, ENSO.	Fishing

Table 3: Disaster Risk Reduction

Title of Case study	**Country/ Region**	**Climate service identified**	**Satellite Component**	**Essential Climate variables addressed**	**Comments**
The Devil's Lake Decision support system – page 120	North Dakota	Flooding, current weather, levels of streams, rivers and lakes	Contribution to short range, long range, seasonal and monthly forecasting, satellite imagery,	Variables related to climate change*	Flood disaster monitoring
Provision of climate services – page 123	Tanzania	Floods, droughts, weather forecasting	Contribution to short range, long range, seasonal and monthly forecasting, tsunami detection	ENSO, Indian Ocean dipole, QBO, precipitation	Tanzania depends on rain-fed agriculture for livelihood.
Developing an early warning system to mitigate temperature stress on rice production – page 127	Japan	Weather forecasting	Contribution to short range, monthly, seasonal and long term forecasting,	Temperatures, winds, seven day mean temp (T7d)	Early warning to avert farming shortcomings
The North America drought Monitor – page 131.	USA, Canada and Mexico	Drought	Standardized prediction index (SPI), Palmer drought index, streamflow. Mountain snow pack, soil moisture, vegetative Health	Temperature (monthly), monthly precipitation,	Drought forecasting/monitor

			Index, etc		
Extreme precipitation event. – page 136	Chile	Detection of: hurricanes, floods, heat waves, droughts	Contribution to weather forecasting,	Extreme weather events (EWEs), precipitation, temperature	Prevention of weather related economic losses and related hazards
Governing drought information systems. – page 139	USA	Drought, streamflow	Soil moisture, vegetation cover, dust,	Temperature, precipitation, wind,	Managing drought risk impacts
Climate services and disaster reduction – page 143	The Caribbean	Flooding/flash flooding, drought,	Contribution to weather forecasting,	Winds, hurricanes, precipitation, landslides, late levels,	Disaster risk reduction
Early warning information on extreme events – page 147	Japan	Weather and climate forecasting	Contribution to short range, monthly, seasonal and long term forecasting	Low temps, high temps, ENSO, seven day mean temp (T7d),	Monitoring extreme events eg temps to support agriculture and health.
Insurance against drought and destabilization of energy – page 150	Uruguay	Weather forecasting	Contribution to short range, monthly, seasonal and long term forecasting	Precipitation, temps, ENSO,	Hydropower generation

Table 4: Water

Title of Case study	**Country/ Region**	**Climate service identified**	**Satellite Component**	**Essential Climate variables addressed**	**Comments**
Helping the world's poorest farmers adapt to a changing climate. *Page 28;* Improved livelihoods and ... page 69*;*	India India, Thailand, Vietnam, China.	Seasonal forecasting	Contribution to seasonal forecasting	Precipitation	Food production and security
Partnerships on water resource management - page 76	France	Short range, daily, weekly, monthly, seasonal, long term forecasts	Contribution to forecasting	Snow, ice, glacier	River flow, soil water, water resource monitoring
Building the seasonal streamflow forecasting service – page 79	Australia	Floods, short range, daily, weekly, monthly, seasonal, long term forecasts	Contribution to forecasting	ENSO	Streamflow information
Developing planning capacity – page 83	Central Asia	Flood, seasonal forecasts	Contribution to forecasting	Glacier, mean temps, annual temps, precipitation	Water resource management
Identifying local climate impacts on weather and water – page 85	Global, USA	Tornadoes, floods, droughts, snowstorms, severe storms, heat waves, lightning	Contribution to forecasting	ENSO, temps, MJO, global sea level, tidal and coastal surges, cloud cover, satellite & reanalysis winds, solar insulation	Wide areas of application
Adaptation to climate change - page 88.	Belarus, Lithuania, Russian Federation	Weather and climate forecasting	Contribution to forecasting	Temperature, precipitation, Monthly, seasonal and	Water resource management

	and Baltic sea			annual weather and climate forecasting parameters	
The Danube River basin climate adaptation strategy.- page 91	19 European countries	Floods, droughts	Contribution to seasonal forecasting	Temp, precipitation, ice, snow cover	Water resource management

b. Energy management

In addition to the “Climate ExChange” articles, papers in the peer reviewed literature are increasingly describing the use of space-based observations to inform end-user decision support. A paper by Eckman & Stackhouse in *Applied Energy* (doi:10.1016/j.apenergy.2011.03.001) described multiple projects coordinated by the Committee on Earth Observation Satellites using space-based data and which are relevant to energy resource assessment in a changing climate. Measurements of solar radiation (derived from multiple Earth radiation budget satellite sensors) and in turn scaled to the Earth’s surface using measurements and satellite-derived climatologies of clouds, ozone, and aerosols; surface winds (from meteorological reanalyses); and a range of other atmospheric parameters (e.g., temperature, relative humidity) are being used to assess the potential of renewable energy resources at a given location across a variety of scales ranging from the individual household to large solar thermal power generation projects. Weather forecasts at various time scales (from daily to seasonal to climatic) are used to optimize load forecasts by power utilities and to better integrate intermittent sources of energy into the electrical grid and for longer-term infrastructure planning. While not strictly related to terrestrial climate change, observations made in the near space environment assist in the prediction of potentially damaging impacts on national grids, particularly at high latitudes near the geomagnetic poles, as a result of solar energetic particle precipitation which follows multiple time scales.

These demonstration projects point to the need for tailored data projects that are easily accessible and useable by non-technical end-users. NASA Langley Research Center produced a 22-year data set of energy-relevant quantities called the Surface Meteorology and Solar Energy (SSE) data set. The long data time series allows for examination of the effects of inter-annual variability and long-term trends, possibly related to climate change impacts. The SSE data have been used by Natural Resources Canada’s RETScreen clean energy project analysis software suite (www.retscreen.net). The global NASA SSE data set augments input parameters in regions where ground-based data are sparse or non-existent.

NASA, DLR, and the École des Mines de Paris, along with other organizations, are working with the International Energy Agency (IEA) to improve solar resource standardization using space-based and surface-based data sources (http://task46.iea-shc.org/). This is an example where a boundary organization like IEA, with connections to multiple government and industry end-users, can improve the uptake and enhance the value of these space-based measurements to a large set of decision making purposes.

4. Efforts to Estimate the Economic Value Space-Based Applications

While somewhat beyond the scope of this paper, attention is drawn to activities that attempt to estimate the value of applications. A NASA Applied Sciences Program funded activity describes socioeconomic impact analysis approaches to value space-based applications, providing a more objective, defensible approach for evaluating Earth observation project impacts on the community (including climate services) (http://appliedsciences.nasa.gov/pdf/SocioeconomicImpactsPrimer.pdf).

Other recent socioeconomic analyses include Dawes et al. (2013) describing the socioeconomic benefit of adding satellite data to the US EPA AirNow program (http://www.ctg.albany.edu/publications/reports/sti_finalreport/sti_finalreport.pdf), the 2012 IEEE conferences to assess socioeconomic benefit for GEOSS (http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=06292266), and the evolving socioeconomic benefits community hosted on http://www.socioeconomicbenefits.org/ .