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INTEGRATION ISSUES

Space-surface Integration (Use of Ground-based AWS Networks)

(Submitted by the WMO Secretariat)

Summary and Purpose of Document

The document summarizes the deliberations of the sixth meeting of the Expert Team on Requirements and Implementation of Automatic Weather Stations (ET-AWS), as regards the potential use of AWS ground-based networks to provide ground-truth for validation of space-based observations.

The paper identifies key observations that would benefit from such AWS measurements. It is furthermore suggested to start a pilot project on a limited geographic area in order to test the concept and better understand how satellite and surface data can best complement each other.

ACTION PROPOSED

In the light of the outcome of ET-AWS-6, the Expert Team is invited to consider the proposal to start a pilot project to investigate how satellite and AWS surface data can best complement each other.

Appendix: Excerpt from the Dossier on the Space-based Component of the GOS

SPACE-SURFACE INTEGRATION (USE OF GROUND-BASED AWS NETWORKS)

Requirements for AWS in support of the validation of space-based observations

(From ET-AWS 6 Final Report)

INTRODUCTION

1. ET-AWS-5 proposed the consideration of using surface-based observations to contribute to the ground-truthing of remotely sensed observations, such as sensors based on satellite platforms.

2. The initiative was welcomed by ET-SAT and ET-SUP to consider the potential of AWS networks to support calibration of space-based observations and product validation. The approach was considered particularly relevant in the context of WIGOS and space-surface integration. However the proposal was lacking in details concerning what networks and surface-based observations could be candidates.

DISCUSSION

3. Recognising that in the "Vision for the Global Observing System in 2025" stated that the surface-based GOS will provide, *inter alia*, data for calibration and validation of space-based data; the following concept should be considered.

4. Modern AWS networks provide the following opportunities.
   a) AWS platforms are able to record, process and transmit observations from a wide range of electronic sensors; these sensors are no longer limited to the standard meteorological variables. Sensors which observe parameters in a manner similar to satellite remotely-sensed observations.
   b) AWS platforms are able to process and transmit data over a range of temporal periods which can be aligned with observation frequency of other systems;
   c) The GTS is capable to transmit messages in BUFR which is flexible and adaptable;
   d) National AWS networks can satisfy international standards for the GOS providing consistency in observation;
   e) AWS networks have a global reach which covers all continents and climates;

5. On the other hand, spaced-based observations in the GOS:
   a) provide spatial coverage at a global scale;
   b) provide gridded observations at specific horizontal and vertical scales and at a observing cycle;
   c) provide geophysical observations which are remotely-sensed and therefore not exactly the same as the traditional observations made by surface networks.

6. The initial proposal was to examine the opportunities for ground-truthing of satellite observations. While this approach may have merit, a broader approach of integration between space-based and surface-based observations may provide greater value to the GOS.

7. The following table lists geophysical parameters which are potentially observed by instruments on satellite platforms (Source: GOS-2010, January - Volume III (Gap Analysis); page 6). The highlighted cells indicate surface parameters which could be potentially observed by automated surface-based instruments on a global scale.

Geophysical parameters addressed by the multi-purpose VIS/IR imagery mission in LEO		
Cloud imagery	Total aerosol optical depth	Snow detection (mask)
Cloud cover (total column)	Total aerosol type	Snow cover
Cloud type	Short-wave cloud reflectance	Snow surface temperature
Cloud optical depth	Downwelling SW irradiance at Earth's surface	Snow albedo
Cloud top height	Downwelling LW irradiance at Earth's surface	Frozen soil and permafrost
Cloud top temperature	Earth's surface albedo	Leaf Area Index (LAI)
Cloud drop effective radius at cloud top	Surface emissivity in TIR window channels	Normalised Difference Vegetation Index (NDVI)
Cloud ice total column	Sea surface temperature	Photosynthetically Active Radiation (PAR)
Cloud ice effective radius at cloud top	Sea-ice surface temperature	Fractional Absorbed PAR (FAPAR)
Water vapour imagery	Sea-ice cover	Fire temperature
Wind vectors in polar regions	Land surface temperature	Fire fractional cover
Water vapour total column	Surface soil moisture (index)	Fire radiative power

Geophysical parameters addressed by the multi-purpose VIS/IR imagery mission in GEO		
Cloud imagery	Total aerosol optical depth	Snow detection (mask)
Cloud cover (total column)	Total aerosol type	Snow cover
Cloud type	Short-wave cloud reflectance	Snow surface temperature
Cloud optical depth	Downwelling SW irradiance at Earth's surface	Snow albedo
Cloud top height	Downwelling LW irradiance at Earth's surface	Frozen soil and permafrost
Cloud top temperature	Earth's surface albedo	Leaf Area Index (LAI)
Cloud drop effective radius at cloud top	Surface emissivity in TIR window channels	Normalised Difference Vegetation Index (NDVI)
Cloud ice effective radius at cloud top	Sea surface temperature	Photosynthetically Active Radiation (PAR)
Water vapour imagery	Sea-ice surface temperature	Fractional Absorbed PAR (FAPAR)
Water vapour total column	Sea-ice cover	Fire temperature
Wind vectors from trace motion	Land surface temperature	Fire fractional cover
Precipitation rate at surface	Surface soil moisture (index)	Fire radiative power
Accumulated precipitation		

8. The document "Evaluation of the potential quality of post-2020 satellite products" (Source: GOS-2010, January - Volume IV (Products)), indicates the following satellite products which have potential to be observed by surface-based instruments. Further information concerning these products is listed in the Appendix.

Ref	**Geophysical parameter**
024	Precipitation rate at surface (liquid or solid)
025	Accumulated precipitation (over 24 hours)
035	Downwelling LW irradiance at Earth's surface
036	Downwelling SW irradiance at Earth's surface
037	Earth's surface albedo
041	Photosynthetically Active Radiation (PAR)
059	Land surface temperature
061	Soil moisture at surface
062	Soil moisture profile (in the roots region)

9. These parameters could potentially be reported by surface-based AWSs at a temporal resolution which could be aligned with the satellite observing cycle.

PROPOSAL FOR A PILOT PROJECT

10. It was proposed that a pilot project be identified where the concept could be tested as a first step. ET-AWS would provide information on potential networks which could complement satellite observations. ET-SAT and ET-SUP would also consider which geophysical observations would potentially benefit the most from this initiative and report back to ET-AWS within the next year.

11. As an example the Joint Commission for Oceanography and Marine Meteorology (JCOMM) and the Drifting Buoy Cooperation Panel (DBCP) are cooperating with the Group for High Resolution SST (GHRSST) and setting up a Pilot Project whereby drifters will be deployed in a specific geographic region in larger quantities to provide for higher spatial and temporal resolution, and higher accuracy SST data. This will permit the refinement of GHRSST products, and better understand how drifter data complement satellite data. Similar approach might be adopted for other variables provided the DBCP Pilot Project is successful. JCOMM is also working with the GHRSST in order to receive appropriate feedback in terms of drifter SST data quality derived from satellite products. This information is useful to buoy operators for taking corrective action (e.g. removing data from GTS distribution for those buoys reporting systematic errors, or correcting their biases).

12. ET-AWS will investigate feasible observations that can contribute to the validation of satellite observations. It requested that ET-SAT identifies geophysical parameters suitable for validation of satellite measurements. It was proposed to start a pilot project similar to the JCOMM one and aimed at validation of satellite products by AWSs.

CONCLUSION

ET-SAT is invited to consider the above proposal and take action as appropriate.

EXCERPT FROM THE DOSSIER ON THE SPACE-BASED COMPONENT OF THE GOS

Vol. IV: Estimated performance of products from typical satellite instruments

024	**Precipitation rate at surface** (liquid or solid)

024.1	***Precipitation radar***
Principle	Backscattered radiation from cloud drops by medium frequency radar (dual-frequency preferred, 14 and 35 GHz). Doppler capability also useful.
Accuracy	Generally good, depending on drop size and liquid/ice ratio.
Coverage	Infrequent, due to limited scanning capability.
Δx	Better at 35 GHz than at 14 GHz, but drawback of saturation for heavy rain.
Conditions	Night and day.
Reference	Applicable only in LEO (see instrument ***19***).

024.2	***MW/Sub-mm sounding***
Principle	MW/Sub-mm radiation in window channels (typically, ~ 10, 19, 37, 90, 150 GHz) with dual polarisation, and absorption bands (typically, ~ 54, 118, 183, 380, 425 GHz). Actually, the precipitation profile is retrieved with the help of an associated NWP model, possibly cloud-resolving.
Accuracy	Depending on drop size and liquid/ice ratio. Lower frequencies more sensitive to liquid water.
Coverage	Frequent, due to cross-nadir relatively large swath (from LEO, often conical scanning).
Δx	Limited by antenna size.
Conditions	Night and day.
Reference	Applicable both in LEO (see instruments ***05*** and ***07***) and GEO (see instrument ***06***).

024.3	***VIS/IR radiometry***
Principle	Inferred from cloud imagery in a few discrete channels selected so as to detect all cloud types, assisted by conceptual models, generally more responsive to convective rain.
Accuracy	Difficult to be stated. Better for convective precipitation. Frequent imagery essential.
Coverage	Frequent, due to large cross-nadir swath of the originating image.
Δx	Several pixels have to be co-processed to have sufficient statistics to derive cluster properties.
Conditions	Night and day. More information available in daylight.
Reference	Applicable only in GEO (see instrument ***02***).

024.4	***Fusion between MW from LEO and IR from GEO***
Principle	Combined product of LEO/MW-derived accurate/infrequent measurements with GEO/IR frequent images used either to be 'calibrated' by MW measurements or to enable dynamical interpolation between MW-derived precipitation data.
Accuracy	Changing with 'distance' from the closest accurate MW determination. Better performance for convective precipitation.
Coverage	Frequent, due to large cross-nadir swath of the originating images.
Δx	Several pixels have to be co-processed to have sufficient statistics to derive cluster properties.
Conditions	Night and day.
Reference	Applicable by using MW in LEO (see instruments ***05*** and ***07***) and IR in GEO (see instrument ***02***).

Estimated potential quality of product "Precipitation rate at surface (liquid or solid)" (> 2020)

Parameter 024	Orbit	Technique	Accuracy (RMS)	Δx (km)	Δz (km)	Δt (h)	Number of sats	Conditions
Precipitation rate at surface (liquid or solid)	LEO	Precipitation radar	10 %	5	-	120	1	-
	LEO	MW radiometry	20 %	10	-	3	8 (GPM)	Heavily model-aided
	GEO	MW/Sub-mm sounding	30 %	10	-	0.25	1	Heavily model-aided
	GEO	VIS/IR radiometry	100 %	10	-	0.1	1	Convection only
	GEO	LEO/MW + GEO/IR fusion	50 %	10	-	0.1	1	Product from data-fusion

025	**Accumulated precipitation** (over 24 hours)

025.1	***From fusion between MW from LEO and IR from GEO***
Principle	Derived by time integration of frequent precipitation rate measured by merging MW precipitation rate data from LEO with IR imagery from GEO. For technique and characteristics, see table 25.4.
Reference	Applicable by using MW in LEO (see instruments ***05*** and ***07***) and IR in GEO (see instrument ***02***).

025.2	***From MW/Sub-mm sounding***
Principle	Derived by time integration of frequent precipitation rate measured by MW/Sub-mm sounders in GEO. For technique and characteristics, see table 25.2.
Reference	Applicable only in GEO (see instrument ***06***).

Estimated potential quality of product "Accumulated precipitation (over 24 hours)**" (> 2020)**

Parameter 025	Orbit	Technique	Accuracy (RMS)	Δx (km)	Δz (km)	Δt (h)	Number of sats	Conditions
Accumulated precipitation (over 24 hours)	GEO	LEO/MW + GEO/IR fusion	50 %	10	-	3	1	Product from data-fusion
	GEO	MW/Sub-mm sounding	30 %	10	-	3	1	Heavily model-aided

035 Downwelling LW irradiance at Earth's surface

035.1	***From IR/MW sounding***
Principle	High-level product derived mostly from atmospheric temperature and water vapour profiles (see tables 001 and 004 respectively). Contributions also from cloud cover profile (table 014), specifically cloud base height (table 015), defective to be observed. Atmospheric modelling necessary.
Reference	Applicable both in LEO (see instruments ***01***, ***03*** and ***05***) and GEO (see instruments ***02***, ***04*** and ***06***).

Estimated potential quality of product "Downwelling LW irradiance at Earth's surface" (> 2020)

Parameter 035	Orbit	Technique	Accuracy (RMS)	Δx (km)	Δz (km)	Δt (h)	Number of sats	Conditions
Downwelling LW irradiance at Earth's surface	LEO	From IR/MW sounding	5 W/m^2	20	-	4	3	Model-aided
	GEO	From IR/MW sounding	5 W/m^2	20	-	0.25	1	Model-aided

036 Downwelling SW irradiance at Earth's surface

036.1	***SW radiometry***
Principle	High-level product derived from observation of scattered solar radiation in several narrow-band channels of VIS, NIR and SWIR to estimate attenuation from clouds and aerosol. Multiple viewing and multi-polarisation help.
Accuracy	Depending on number and bandwidths of channels and on the atmospheric model utilised.
Coverage	Frequent, due to cross-nadir large swath.
Δx	Several pixels have to be co-processed to search for the least contaminated from clouds.
Conditions	Daylight only. Cloud-free or broken cloudiness.
Reference	Applicable both in LEO (see instrument ***01*** and ***16***) and GEO (see instrument ***02***).

Estimated potential quality of product "Downwelling SW irradiance at Earth's surface" (> 2020)

Parameter 036	Orbit	Technique	Accuracy (RMS)	Δx (km)	Δz (km)	Δt (h)	Number of sats	Conditions
Downwelling SW irradiance at Earth's surface	LEO	SW radiometry	10 W/m^2	4	-	4	3	Clear-air, model-aided
	GEO	SW radiometry	15 W/m^2	8	-	0.1	1	Clear-air, model-aided

037 Earth's surface albedo

037.1	***SW radiometry***
Principle	High level product after measuring scattered solar radiation in several channels of VIS under several viewing angles and solar angles to estimate anisotropy effects and improve radiative fluxes computations. Channels for atmospheric corrections also included.
Accuracy	Depending on the number of different viewing conditions and the atmospheric model utilised.
Coverage	Infrequent, due to the need for collecting observations under different viewing conditions.
Δx	Several pixels have to be co-processed to search for the least contaminated from clouds.
Conditions	Daylight only. Cloud-free or broken cloudiness.
Reference	Applicable both in LEO (see instruments ***01*** and ***16***) and GEO (see instrument ***02***).

Estimated potential quality of product "Earth surface albedo" (> 2020)								
Parameter 037	**Orbit**	**Technique**	**Accuracy (RMS)**	**Δx (km)**	**Δz (km)**	**Δt (h)**	**Number of sats**	**Conditions**
Earth's surface albedo	LEO	Multi-view SW radiometry	1 %	10	-	168	1	Clear-air, model-aided
	LEO	SW radiometry	3 %	4	-	168	3	Clear-air, heavily model-aided
	GEO	SW radiometry	5 %	8	-	72	1	Clear-air, heavily model-aided

041 Photosynthetically Active Radiation (PAR)

041.1	***VIS radiometry***
Principle	High-level product similar to "37 - Downwelling short-wave irradiance at Earth surface" except that it refers to the interval 0.4-0.7 μm used by vegetation for photosynthesis.
Accuracy	Depending on information on clouds and aerosol and on the atmospheric model utilised.
Coverage	Frequent, due to cross-nadir large swath.
Δx	Several pixels have to be co-processed to search for the least contaminated from clouds.
Conditions	Daylight only. Cloud-free or broken cloudiness.
Reference	Applicable both in LEO (see instruments ***01*** and ***16***) and GEO (see instrument ***02***).

Estimated potential quality of product "Photosynthetically Active Radiation (PAR)" (> 2020)								
Parameter 041	**Orbit**	**Technique**	**Accuracy (RMS)**	**Δx (km)**	**Δz (km)**	**Δt (h)**	**Number of sats**	**Conditions**
Photosynthetically Active Radiation (PAR)	LEO	VIS radiometry	10 W/m^2	4	-	4	3	Clear-air, model-aided
	GEO	VIS radiometry	10 W/m^2	8	-	0.1	1	Clear-air, model-aided

059 Land surface temperature

059.1	***IR radiometry***
Principle	Derived from IR imagery in a number of channels including "windows" and other ones necessary to evaluate emissivity and atmospheric attenuation (from water vapour). Dual-view improves the accuracy of atmospheric correction,
Accuracy	Depending on number of channels and the knowledge (or estimate) of emissivity.
Coverage	Frequent, due to large cross-nadir swath of the originating image.
Δx	Several pixels have to be co-processed to search for the least contaminated from clouds.
Conditions	Night and day. Cloud-free or broken cloudiness.
Reference	Applicable both in LEO (see instrument ***01***) and GEO (see instrument ***02***).

059.2	***IR spectroscopy***
Principle	Derived from the multiple number of narrow windows through the IR spectrum, associated to all possible information on atmospheric corrections. This enables to estimate emissivity.
Accuracy	Good, compatibly with the larger IFOV of sounders as compared to imagers.
Coverage	Frequent, due to large cross-nadir swath.
Δx	Several pixels have to be co-processed to search for the least contaminated from clouds.
Conditions	Night and day. Cloud-free or broken cloudiness.
Reference	Applicable both in LEO (see instrument ***03***) and GEO (see instrument ***04***).

059.3	***MW radiometry***
Principle	Emitted and scattered MW radiation in atmospheric windows at low-medium frequencies (e.g., 5, 10 GHz). More polarisations needed, to correct for wetness effects.
Accuracy	Depending on wetness and vegetation. Good for bare and dry soil.
Coverage	Frequent, due to relatively large cross-nadir swath (conical scanning used).
Δx	Limited by antenna size.
Conditions	Night and day. All weather.
Reference	Applicable only in LEO (see instrument ***08***).

Estimated potential quality of product "Land surface temperature" (> 2020)								
Parameter 059	**Orbit**	**Technique**	**Accuracy (RMS)**	**Δx (km)**	**Δz (km)**	**Δt (h)**	**Number of sats**	**Conditions**
Land surface temperature	LEO	IR radiometry	2 K	8	-	4	3	Clear-air

	GEO	IR radiometry	4 K	24	-	0.1	1	Clear-air
	LEO	IR spectroscopy	1 K	20		4	3	Clear-air
	GEO	IR spectroscopy	1 K	20		0.25	1	Clear-air
	LEO	MW radiometry	1 K	50	-	8	3	All weather

061 Soil moisture at surface

061.1	*MW radiometry*
Principle	Emitted MW radiation at low frequencies (e.g., 1.4 and 2.7 GHz). More polarisations needed, to correct for roughness effects. More channels desirable, to correct for temperature. Higher frequencies (5, 10 GHz) also useful, particularly for bare soil.
Accuracy	Good at lower frequencies, progressively worse at higher frequencies (vegetation sensitive).
Coverage	Frequent, due to relatively large cross-nadir swath (conical scanning used).
Δx	Limited by antenna size. Synthetic aperture possible, at the expenses of sensitivity.
Conditions	Night and day. All weather.
Reference	Applicable only in LEO (see instrument ***08***).

061.2	*Radar scatterometry*
Principle	Backscattered MW radiation at relatively low frequencies (e.g., 5 GHz). The multiple viewing angle capability is exploited to correct for roughness.
Accuracy	Good for bare soil.
Coverage	Frequent, due to relatively large cross-nadir swath.
Δx	Limited by antenna size.
Conditions	Night and day. All weather.
Reference	Applicable only in LEO (see instrument ***12***).

061.3	*SAR imagery*
Principle	Backscattered MW radiation at frequencies 1.3 or 5 or 11 GHz collected by synthetic aperture radar.
Accuracy	Lower frequencies have better performance, especially over vegetation.
Coverage	Infrequent, due to limited cross-track swath and limited instrument duty cycle.
Δx	Synthesised by signal processing. Relatively good resolution used for this purpose.
Conditions	Night and day. All weather.
Reference	Applicable only in LEO (see instrument ***29***).

061.4	*VIS/IR radiometry*
Principle	Several proxies possible. Examples: damping of reflectivity from VIS/NIR to SWIR; from Apparent Thermal Inertia (ATI) derived by measuring the delay of land temperature rising in response to incoming solar radiation (valid for bare soil).
Accuracy	Discontinuous, depending on knowledge of soil structure and conditions.
Coverage	Frequent, due to large cross-nadir swath of the originating image.
Δx	Several pixels have to be co-processed to search for the least contaminated from clouds.
Conditions	Daylight only, following soil heating. Cloud-free or broken cloudiness.
Reference	Applicable both in LEO (see instrument ***01***) and GEO (see instrument ***02***).

Estimated potential quality of product "Soil moisture at surface" (> 2020)

Parameter 061	Orbit	Technique	Accuracy (RMS)	Δx (km)	Δz (km)	Δt (h)	Number of sats	Conditions
Soil moisture at surface	LEO	MW radiometry	5 $m^3 \cdot m^{-3}$ %	30	-	8	3	All weather, vegetation-sensitive
	LEO	Radar scatterometry	5 $m^3 \cdot m^{-3}$ %	20	-	36	1	All weather, vegetation-sensitive
	LEO	SAR imagery	10 $m^3 \cdot m^{-3}$ %	0.1	-	360	2	All weather, vegetation-sensitive
	LEO	VIS/IR radiometry	50 $m^3 \cdot m^{-3}$ %	4	-	4	3	Clear-air, vegetation-sensitive
	GEO	VIS/IR radiometry	50 $m^3 \cdot m^{-3}$ %	12	-	0.1	1	Clear-air, vegetation-sensitive

062 Soil moisture profile (in the roots region) (required from surface to 2 m below)

062.1	*L-band MW radiometry*

Principle	Emitted MW radiation at low frequencies (e.g., 1.4 GHz). More polarisations needed, to correct for roughness effects.
Δz	Reconstructed by modelling in a depth of about 2 m below surface.
Accuracy	Good except for thick forests.
Coverage	Frequent, due to relatively large cross-nadir swath (conical scanning used).
Δx	Limited by antenna size. Synthetic aperture used.
Conditions	Night and day. All weather.
Reference	Applicable only in LEO (see instrument ***08***).

062.2	***L-band SAR imagery***
Principle	Backscattered MW radiation at low frequency (typical, 1.3 GHz) collected by SAR. Lower frequency (P-band, ~ 300 MHz) also possible.
Δz	Reconstructed by modelling in a depth of about 2 m below surface.
Accuracy	Good except for thick forests, that would require P-band.
Coverage	Infrequent, due to limited cross-track swath and limited instrument duty cycle.
Δx	Synthesised by signal processing. Relatively good resolution used for this purpose.
Conditions	Night and day. All weather.
Reference	Applicable only in LEO (see instrument ***29***).

Estimated potential quality of product “Soil moisture profile” (> 2020)

Parameter 062	Orbit	Technique	Accuracy	(RMS)	Δx (km)	Δz (km)	Δt (h)	Number of sats	Conditions
Soil moisture profile (in the roots region) Surface to 2 m below	LEO	L-band MW radiometry	5	$m^3 \cdot m^{-3}$ %	50	0.0001	72	1	All weather, model-aided
	LEO	L-band SAR imagery	10	$m^3 \cdot m^{-3}$ %	0.1	0.0001	1440	1	All weather, model-aided