Response to "**Initial Request for White Papers**" for NRC's "**Preparing for Initiation of the 2017-2027 NRC Decadal Survey in Earth Science and Applications from Space**"

The Aspects of Integration of the Satellite platforms as well as including In-Situ Platforms for Global Gridded Products of Various Resolutions

- Sea surface wind and sea surface temperature examples

Huai-Min Zhang, John J. Bates, …
NOAA National Centers for Environmental Information, Asheville, NC

1. Introduction

This draft "White Paper" is in response to the "Initial Request for White Papers" for NRC's "Preparing for Initiation of the 2017-2027 NRC Decadal Survey in Earth Science and Applications from Space". The scope of this paper is in the aspects of the integration of observations from various satellite platforms as well as integration of satellite and in-situ platforms for practical global gridded and blended production for supported highest resolutions and accuracy as possible. The points of this paper are illustrated by two examples. The first example is a blended global sea surface wind product by integrating satellite platforms. The 2nd example is on the integration of satellite and in-situ platforms for climate scale sea surface temperature purpose. Recently, the National Academies of Sciences (NAS) commissioned the Committee on a Framework for Analyzing the Needs for Continuity of NASA-Sustained Remote Sensing Observations of the Earth from Space. This Committee produced a draft publication on "Continuity of NASA Earth Observations from Space: A Value Framework". Our proposed scope here also fits to this NAS report's element "2.2 Continuity", in the sense that "Scientific understanding of global change requires long-term, reliable measurements of the key physical variables that define the variability and shifts in state of the Earth system and its multiple components", and the Committee's "Finding: Continuity of an Earth measurement exists when the quality of the measurement for a specific quantified science objective is maintained over the required temporal and spatial domain set by the objective. The quality of a measurement is characterized by its combined standard uncertainty, which includes instrument calibration uncertainty, repeatability, time and space sampling, and data systems and delivery for climate variables (algorithms, reprocessing, and availability)—each of which depends on the scientific objective. "

The Earth's weather and climate system is driven by two major constantly changing components – the atmosphere and the ocean. These two components vigorously interact with each other over about 70% of the Earth's surface and these interactions directly regulate the Earth's water and energy cycles. Advances in understanding this coupled system and improvements in numerical weather and ocean forecasts demand increasingly higher resolution data on wind and air-sea fluxes, as documented in several World Meteorological Organization (WMO) programs (e.g., World Meteorological Organization, 2000; Curry et al., 2004; Large et al., 1991). Some of the applications require temporal and spatial resolutions of up to 3 hours and 50 km. However, the extent these requirements can be met in reality are constrained by the existing global observing system of multiple satellites and in-situ observations. Two aspects of this are: 1) Given the existing observation systems (satellite + in-situ), the resolutions of product/dataset generation have to be supported by the adequacy of the existing observations, to reduce aliases and noises by undersampling. 2) In the future design of space-based observations/satellites, the system design has to take the need of dataset productions for real world applications into account. Here we illustrate the above by two examples: a) the multiple-satellite blended sea surface winds; and b) integrated design of satellite and in-situ observing systems for climate scale sea surface temperature.

2. Relationship Between Product Resolutions and Available Satellites and Their Orbit Configurations: Global Blended Sea Surface Wind Example

Sea surface wind speed has been operationally observed from satellite sensors, starting with a US Defense Meteorological Satellite Program (DMSP) satellite F08 in July 1987 to the constellation of 5 or more US satellites since 2000. In this satellite era, in-situ observations still play a critical role in calibrating and validating satellite observations. However, with the dense satellite sampling, in-situ observations play a minor role in reducing random and sampling errors in blended analyses using in-situ and satellite observations. Thus in this data sampling example, we only consider satellite observations.

Among these satellites are the passive DMSP observations from the microwave radiometers on the Special Sensor Microwave Imager. Later additions to these passive microwave observations are the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) and the Advanced Microwave Scanning Radiometer of NASA’s Earth Observing System. The scatterometer (e.g., the Quick Scatterometer (QuikSCAT)), which is active by nature, uses microwave radar and retrieves both wind speed and wind direction.

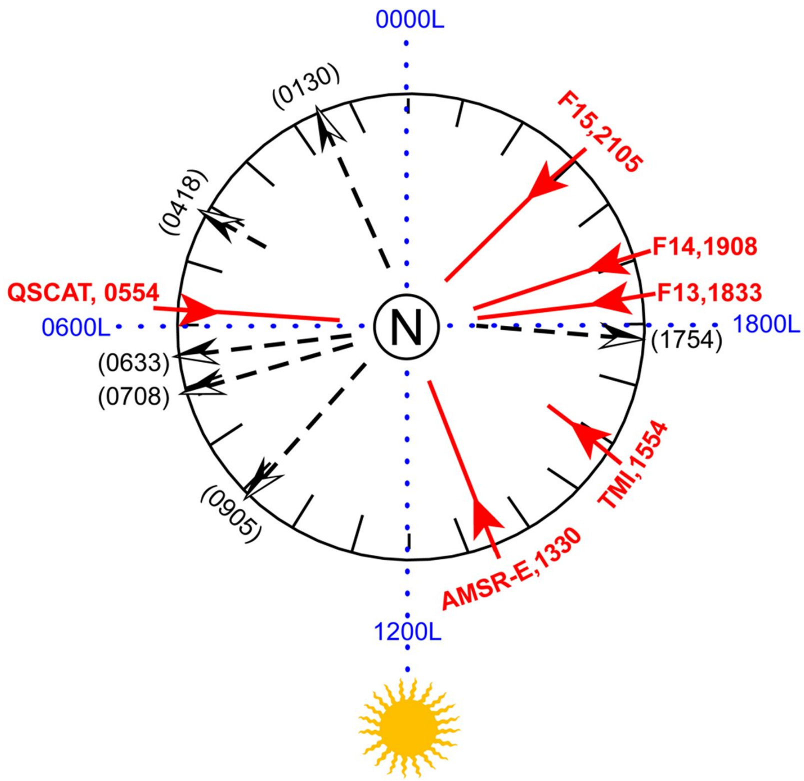

Fig.1: An example of a simplified view looking down at the North Pole of the satellite observations in Local Solar Time (LST) of January 2005. Solid lines and arrows indicate ascending tracks and dashed lines and open arrows indicate descending tracks.

Here we show the temporal improvement of the composite global data sampling rate from the above satellites (Zhang et al. 2006). We show the possibility of producing blended global products on a 0.25 global grid for various temporal resolutions. This 0.25 spatial grid marginally resolves ocean boundary currents such as the Gulf Stream where large turbulent fluxes and large flux gradients frequently occur

Table 1. Typical percentages of the global 0.25º oceanic boxes between 65ºS – 65ºN in which there are data coverage 75% of the time or better for the specified time resolutions (1st column) and as functions of time (indicated by the top row). The whole time period is classified into six stages corresponding to the typical number of available satellites. The time periods with ≥ 90% spatial coverage and ≥75% temporal coverage are highlighted by yellow shading.

Time period & satellites / Time resolution	JUL1987→ I F08	JAN1991→ II F10, F11	JUN1995→ III F10, F11, F13	JAN1998→ IV F11,F13, F14 TMI	JAN2000→ V F13, F14, F15 TMI, QSCAT	JUN2002→ VI F13, F14, F15 TMI, QSCAT AMSR-E
6-hourly	12	26	42	56	66	91
12-hourly	27	72	97	99	100	100
daily	75	100	100	100	100	100

From the above, we re-emphasize two points: 1) Given the existing observation systems (satellite + in-situ), the resolutions of product/dataset generation have to be supported by the adequacy of the existing observations, to reduce aliases and noises by undersampling. 2) In the future design of space-based observations/satellites, the system design has to take the need of dataset productions for real world applications into account.

3. Integration of Satellite and In-Situ Observations: Sea Surface Temperature Example for Global Climate Monitoring and Research

The WMO Global Climate Observing System (GCOS) consists of several components, including strategic planning, system design and implementation, and effective data integration and dissemination. Efficient management of sustained observing system operations requires continuous monitoring, evaluation, and periodic reviews.

Climate change indicators include oceanic and atmospheric temperature variability at timescales longer than weather-related fluctuations (typically less than a week). Temperature changes at the Earth's surface (over both land and ocean) have been the prominent indicators in many climate change assessments because surface observations have the longest records and thus provide a historical context for climate change. In this paper, the term "climate assessment" refers to climate trends and variability from observational data, but it does not include attribution of the causes of climate change (Zhang et al., 2009).

The modern SST observing system mainly consists of in situ observations (from ships and buoys) and satellite remote sensing. Since the satellite instruments became operational in 1981, satellite observations have provided dramatically improved coverage in time and space. The increased data coverage assures adequately small analysis errors in objectively analyzed SST fields by blending satellite and in situ observations. However, adequate in situ observations are still needed to correct systematic biases associated with satellite retrieval algorithms. These biases occur for both infrared and microwave retrievals. Infrared retrievals are impacted by cloud and aerosol contamination, while microwave retrievals are impacted by precipitation and land contamination.

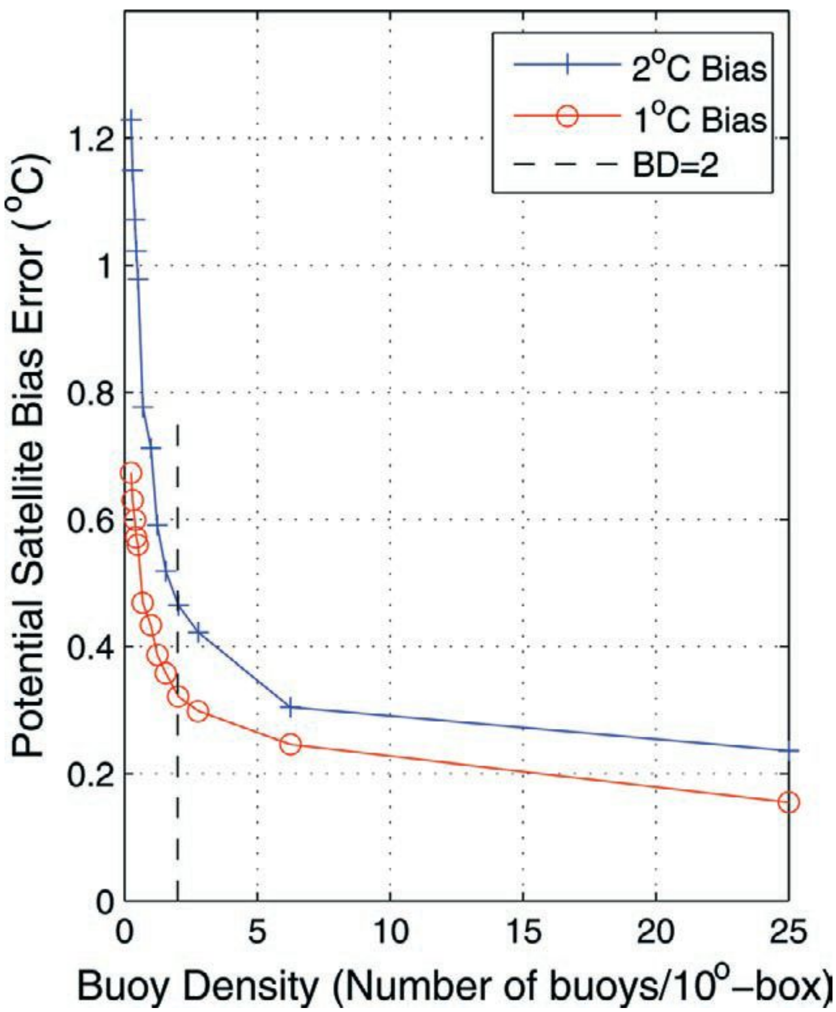

Fig.2: Potential satellite bias reduction versus needed in-situ data/buoy data density.

One study for AVHRR SST used Monte Carlo simulations to determine the relationship between the residual satellite bias and in situ data density, as shown in Fig. 2. It shows the near-exponential bias reductions as the BD increases from zero. Rapid error reductions occur when the BD increases from 0 to a BD between 2 and 5; further increase in the BD only results in minimal reductions in the PSBE. Coincidently, a BD of 2 reduces the maximum bias from 2°C (at BD = 0) to about 0.5°C, which is the upper limit of the GCOS/GOOS requirement. Thus, a BD of 2 is regarded as the minimum acceptable density.

The above observing system has been operationally implemented as US/NOAA's contribution to GCOS. However, the above only used AVHRR satellite observations. If two types of satellite instruments are present with independent error characteristics (e.g., infrared and microwave), the PSBE error could be reduced. In addition to the operational AVHRR SST observations since the early 1980s, microwave observations became available between 38°S and 38°N from the National Aeronautics and Space Administration's (NASA) Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) beginning in December 1997 and globally from NASA's Advanced Microwave Scanning Radiometer (AMSR) beginning in June 2002. Other global microwave satellite SST instruments before 2002 were either poorly calibrated or lacked the low-frequency channels that were needed by the SST retrieval algorithm [e.g., the Special Sensor Microwave Imager (SSM/I)]. Additional microwave SST instruments have recently become available and more are planned, as well as more recent improved VIIRS observations. Therefore there is a need to reevaluate the above integrated Situ-Satellite observing systems.

References:

Curry, J. A., et al. (2004), SEAFLUX, Bull. Am. Meteorol. Soc., 85(3), 409– 424.

Large, W. G., W. R. Holland, and J. C. Evans (1991), Quasi-geostrophic response to real wind forcing: The effects of temporal smoothing, J. Phys. Oceanogr., 21, 998–1017.

National Academies of Sciences, Engineering, and Medicine. 2015. Continuity of NASA Earth Observations from Space: A Value Framework. Washington, DC: The National Academies Press (publication draft)

World Meteorological Organization (2000), Final report of the Joint WCRP/SCOR Working Group on Air-Sea Fluxes (SCOR Working Group 110): Intercomparison and validation of ocean-atmosphere energy flux fields, WMO/TD-1036/WCRP-112, 303 pp., Geneva.

Zhang, H.M., J.J. Bates, R.W. Reynolds, 2006: Assessment of composite global sampling: sea surface wind speed. Geophys. Res. Lett., doi: 10.1029/2006GL027086

Zhang, H.-M., R.W. Reynolds, R. Lumpkin, R. Molinari, K. Arzayus, M. Johnson, T.M. Smith, 2009: An Integrated Global Ocean Observing System for Sea Surface Temperature Using Satellites and In situ Data: Research-to-Operations, Bull.Ameri. Meteorol. Soc., 90 (No. 1), DOI:10.1175/2008BAMS2577.1