Specification for Sea Surface Temperature (DRAFT)

Sea-surface temperature (SST) is a vital component of the climate system as it exerts a major influence on the exchanges of energy, momentum and gases between the ocean and atmosphere. These heat exchanges are a main driver of the global weather systems. The spatial patterns of SST reveal the structure of the underlying ocean dynamics. SST is a complex quantity as it not only controls fluxes, but also responds to turbulent and radiative exchanges at the surface. The value of the SST depends therefore on where and how the measurement is taken. In situ measurements comprise a database that currently extends back to the late 18th century, with the prospect of additional recovered and digitized historical measurements being added. Over this time period, the types of available measurements and their areal coverage are changing significantly. In the past 30 years, near-global sampling of SST has become available on daily to weekly basis due to the advent of infrared radiometers on polar-orbiting and geosynchronous satellites and of microwave radiometers on polar-orbiting satellites. These in situ and satellite-based measurements are complementary, each type providing supporting information of use to the other. For climate applications, the accuracy requirements set by GCOS are very stringent, being an absolute accuracy of 0.1K, with stability at the level of 0.03K/decade, both over space scales of ~100-1000 km. The Group for High Resolution SST (GHRSST; www.ghrsst.org) is an international consortium of scientists and operational practitioners focused on SST derivation and applications. It helps coordinate research into and applications of SST measurements from both satellite and in situ sources. Efforts are underway to recover more historical data and incorporate them into the EOV. The provision of metadata describing the measurement approach and, where relevant, conditions under which the measurements were taken are an important component of all data sets. The long-term stewardship of all datasets is critical.

EOV Information	
Name of EOV	Sea-surface temperature (SST)
Sub-Variables	Skin SST, subskin SST, foundation SST, Temperature at stated depth. The legacy "bulk SST" variable refers to the subsurface temperature at (usually unspecified_ depth in the range from 0.5 m to a few meters. See https://www.ghrsst.org/science-and-applications/sst-definitions/ for further details.
Derived Products	Momentum, sensible and latent turbulent heat fluxes to the atmosphere. Height-adjusted version of other variables (e.g. wind speed, air temperature and humidity. Electromagnetic emission (long-wave fluxes). Mixed layer heat content.
Supporting variables	Physical retrievals of top-of-atmosphere radiances, Bayesian cloud masking, and conversion from skin SST to temperature at depth require atmospheric state and wind data (e.g. from NWP models and reanalyses). To make an appropriate use of in situ data, depth of measurement is needed.
Contact/Lead Expert(s)	Group for High Resolution Sea Surface Temperature (GHRSST). CEOS SST Virtual Constellation JCOMM DBCP and SOT

Draft Template for Essential Ocean Variables

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Requirements Settings	
Responsible GOOS Panel	OOPC
Reporting Mechanism(s)	Requirements collated by CEOS SST-VC and GHRSST based on documents, reports and web pages, and user interactions. Publications in the reviewed literature.
Readiness Level [1]	Mature
Societal Benefit Area(s) **Societal drivers**	Improved weather and ocean forecasting; operational oceanography, monitoring and research of climate variability and change; fisheries management; coral reef monitoring; coastal management decision support.
Scientific Application(s)	Oceanography, operational oceanography, weather prediction, ocean state, air-sea interactions, climate research

Phenomena to capture.	Diurnal variability	Mesoscale & sub-mesoscale ocean variability	Seasonal variability	Inter-annual variability	ENSO	Climate variability
Temporal Scales of the phenomena	Minutes to a day	Days to months	Weeks to year	Months to years	Weeks to months	Years to decades and longer
Spatial scales of phenomena	<1-100km	<1-500km	100-1000km	100-1000km	100-10000km	100-10000km
Magnitudes/ range of the signal, thresholds to capture	0.01 to 7K	0.01 to 5K	0.01 to 5K	0.01 to 3K	0.01 to 5K	0.01 to 0.5K

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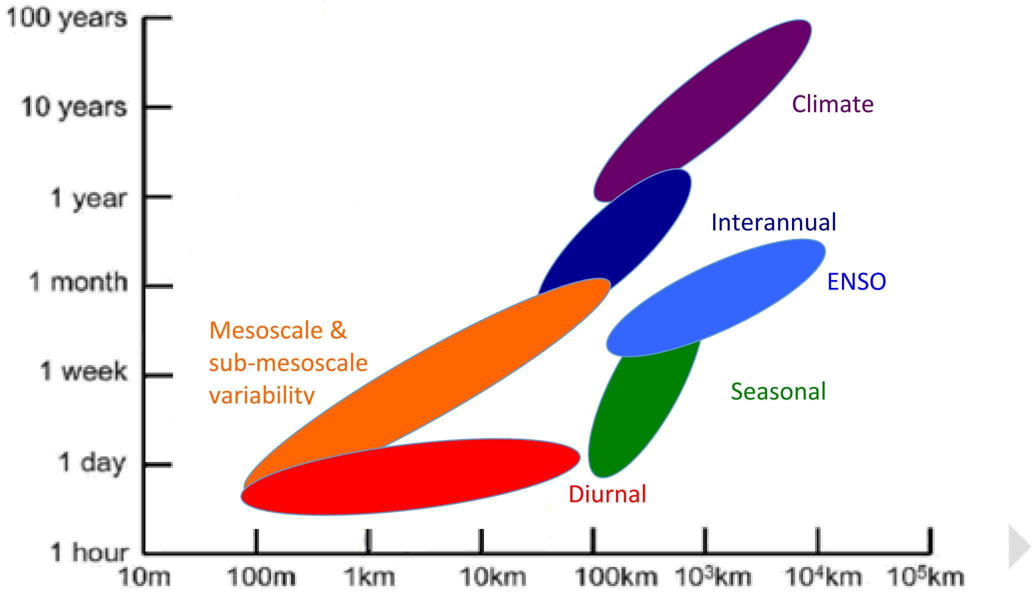

Figure 1: Scales of phenomena related to sea-surface temperature.

Figure 2: Insert map to illustrate regional variations in requirements (optional).

Observation Deployment & Maintenance – I				
Observing Elements	Infrared satellite radiometers	Microwave satellite radiometers	Infrared ship radiometers	Ship thermometers
Phenomena addressed	Skin SST	~Subskin SST	Skin SST	SST_{depth} (possibly, unspecified depth)
Readiness Level	Mature	Mature	Mature	Mature
Spatial sampling	~1km; global coverage	Typically on a 25km grid (but not independent of neighbours)	0.01 – 1km along ship tracks	0.01 – 100km along ship tracks
Temporal sampling	~15 Minutes (geostationary) to ~12 hr (Polar orbiter) Latitude dependent	~12 hr. Latitude dependent	Minutes	Minutes to hours
Special Characteristics/ Contributions	On polar-orbiting and geostationary satellites, sampling of diurnal variability by polar orbiters determined by orbit. SST not retrieved under cloud.	On polar-orbiting satellites; sampling of diurnal variability determined by orbit. SST not retrieved under precipitating cloud or close to coasts.	Mounted on selected ships	Concentrated in shipping lanes. Elsewhere from mainly research ships. Provides a centennial-scale record and the means to link satellite observations to it.
Relevant measured variables	Top-of-atmosphere radiances	Top-of-atmosphere radiances	Sea-surface emission in the infrared	T at stated depth
Sensor(s)/ Technique	Infrared multi-spectral radiometers. Cloud screening & atmospheric correction algorithms to derive skin SST.	Microwave multi-spectral radiometers. Various algorithms to derive subskin SST, and other geophysical variables.	Measurements of incident sky radiation also needed to correct for reflected sky radiance.	Contact thermom-eters in a range of mounting configurations; variety of traditional methods: buckets, engine room intake, hull thermometers.
Accuracy/ Uncertainty estimate (units). *	0.2-0.5K rms	0.5K rms	0.1K rms	0.01-0.75K rms

* There are components that have different levels of correlation in space and time, so aggregating these numbers is not straightforward.

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Observation Deployment & Maintenance – II				
Observing Elements	Moorings	Drifters	AUVs (gliders) and Argo profilers	Marine mammals and Sea-birds
Phenomena addressed	SST_{depth} (possibly, unspecified depth)	SST_{depth} (possibly, unspecified depth)	SST_{depth}	SST_{depth} (possibly, unspecified depth)
Readiness Level	Mature	Mature	Mature	Mature
Spatial sampling	Point measurement; variable spatial resolution, concentrated in tropics and coastal areas	Point measurement; Variable resolution along drift track, extensive coverage.	Point measurement; Variable resolution along track. (SST from Argo limited to where water depths >2000m)	Point measurement; Variable resolution.
Temporal sampling	Minutes to hours	Minutes to hours	Every ten days (Argo) and variable (gliders)	Variable
Special Characteristics/ Contributions	Decadal data in the tropics. Provides stability reference in the tropical Pacific for satellite data; this is threatened by current servicing arrangements.	Variable temporal & spatial distributions. Provides link between satellite data and longer historical record. Currently most numerous in situ measurements.	Variable temporal & spatial distributions	Variable temporal & spatial distributions
Relevant measured variables	T at stated depth	T at stated depth	T at stated depth	T at stated depth
Sensor(s)/ Technique	Contact thermometers, at depths of 0.1 to a few m	Contact thermometers, at ~0.2m depth.	Contact thermometers, at ~5m depth. Some take measurements to surface.	Contact thermometers on head of mammals and legs of large sea-birds (e.g. albatrosses).
Accuracy/ Uncertainty estimate (units).*	0.01-0.5K rms	0.1-0.25K	0.01K or better	0.01K or better to 0.1K

* There are components that have different levels of correlation in space and time, so aggregating these numbers is not straightforward.

Future observing Elements					
Observing Elements	Next Generation Drifters	Infrared Radiometers on UAVs			
Readiness Level [1]	Pilot	Pilot			
Spatial sampling	Variable	Continuous along flight path			
Temporal sampling	Minutes to hours	Continuous along flight path			
Special Characteristics/ Contributions	Improved calibration of thermometers	Light-weight imaging			
Estimated time when part of the observing system	Currently being deployed	Currently deployed.			
Relevant measured parameter(s)	T_{depth}	Skin SST			
Sensor(s)/Technique	Contact thermom-eters, at ~0.2m depth.	Infrared radiometers, some imaging.			
Accuracy/Uncertainty estimate (units).	0.05K	0.1K or better			

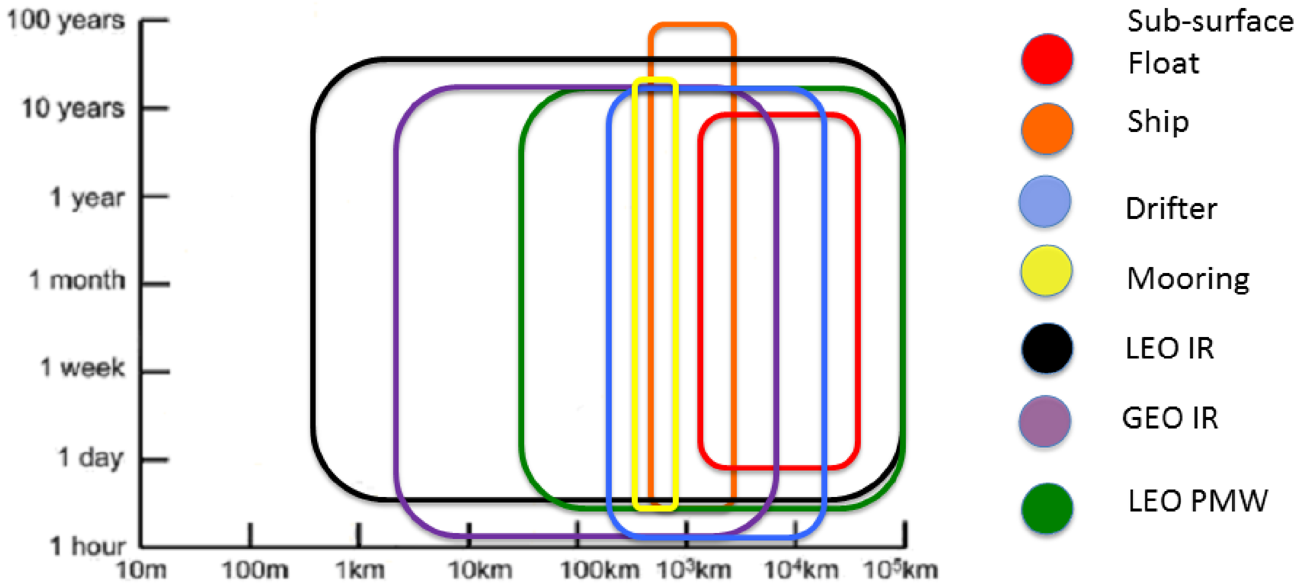

Figure 3a. Measurement scales of the component networks. The scales of individual measurements are indicated by the positions of the bottom-left of each box, and the largest scales sampled by a network of sensors by the top right.

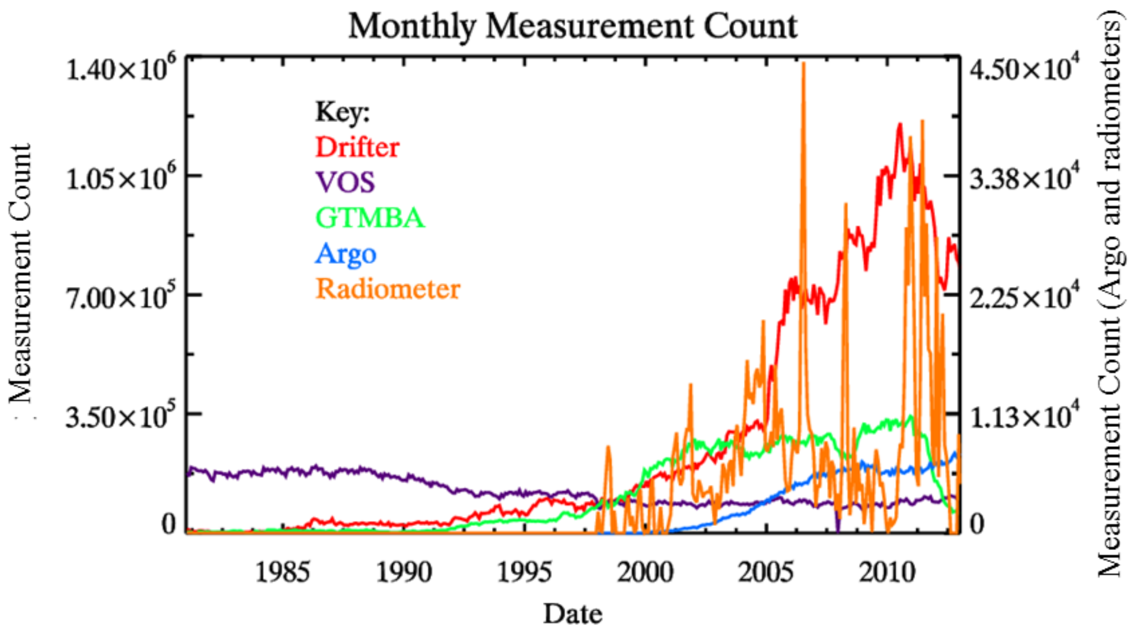

Figure 3b. Time-series of monthly measurement counts for components of the in situ network. VOS means Voluntary Observing Ships; GTMBA the Global Tropical Moored Buoy Array; Radiometer indicates those mounted on ships. Note year-to-year variations, especially the recent drop in numbers from the GTMBA and drifters. (NB, the numbers of Argo and Radiometer measurements are given on the stretched scale on the right-hand axis.)

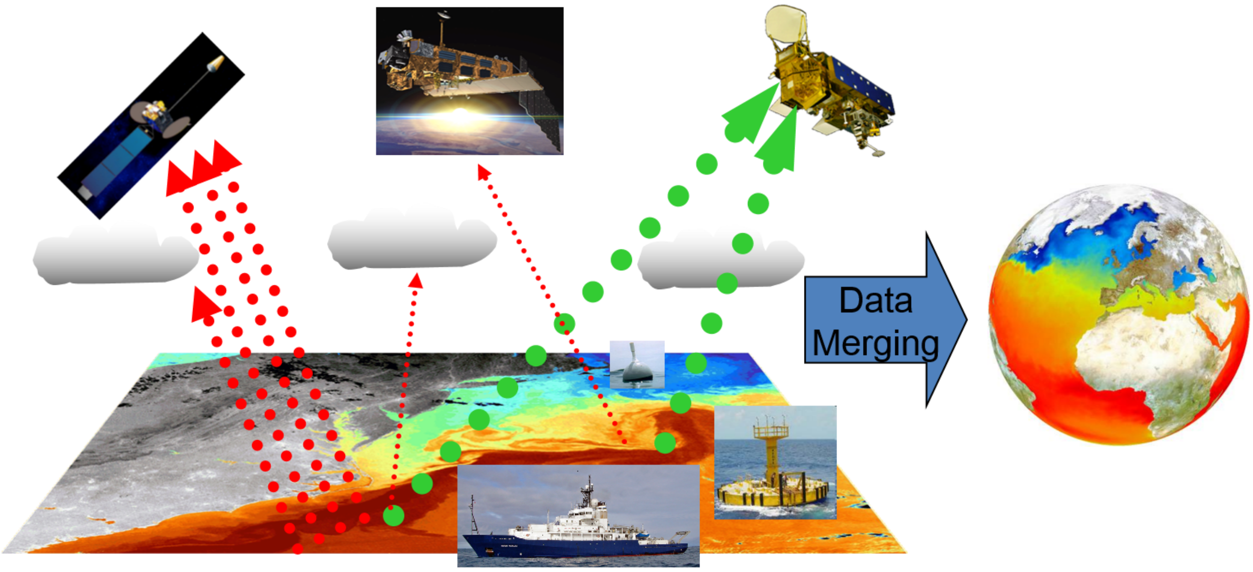

Figure 4a. Schematic of the SST observing system. Infrared radiometers on polar-orbiting satellites have good spatial resolution in cloud-free conditions, and some have very good accuracy; those on geostationary satellites have high temporal sampling (but again restricted to cloud-free conditions). Microwave radiometers on polar-orbiting satellites provide data though clouds, except those with heavy precipitation, but have poorer spatial resolution and cannot retrieve SSTs close to land. In situ data, from drifting, profiling and moored buoys, and AUVs, are generally not limited by clouds and rain, but have comparatively irregular and spatial sampling. All components of the satellite and in situ networks contribute the SST EOV.

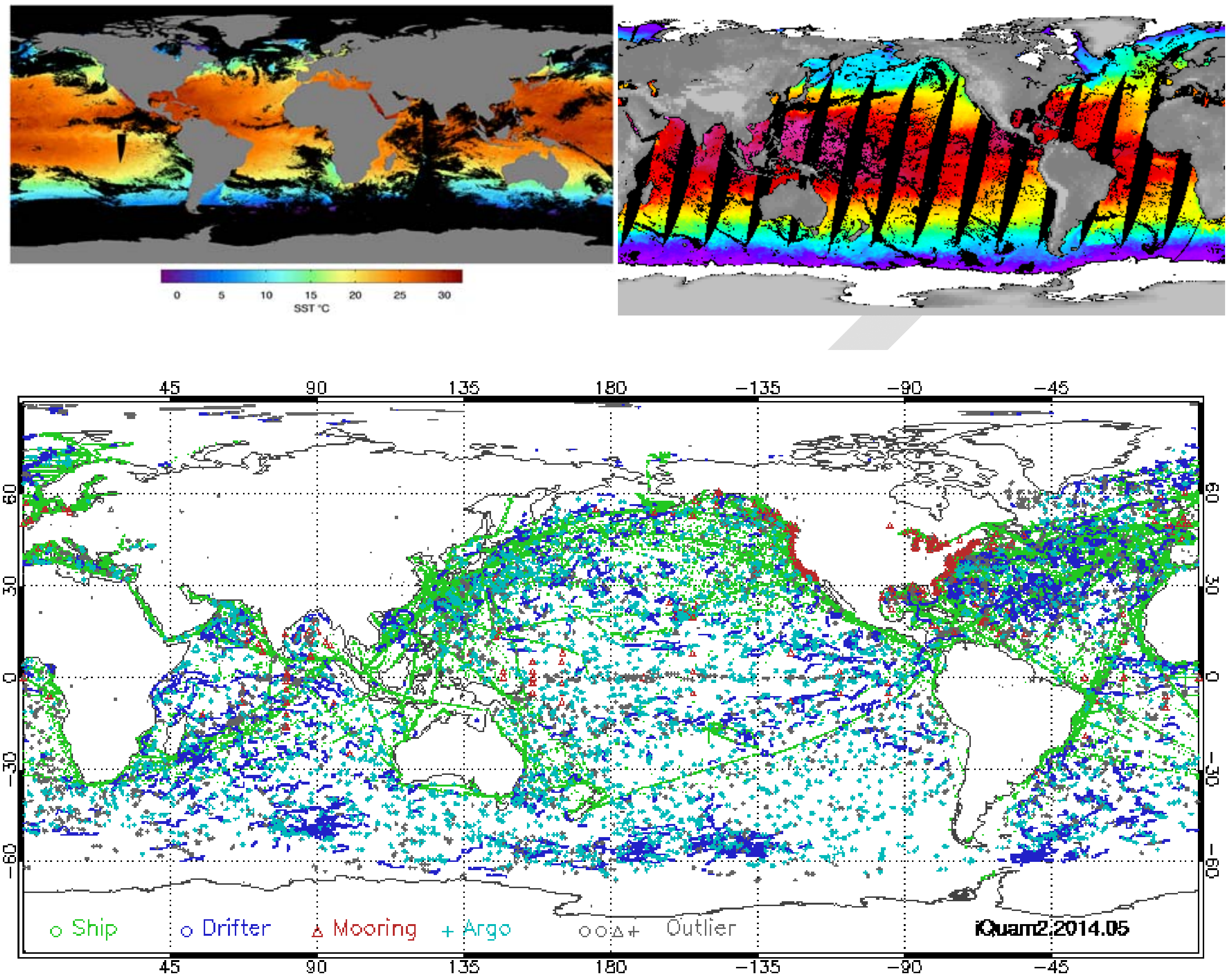

Figure 4b: Maps indicating the coverage of the global oceans from geostationary satellites (top left; daily measurements; courtesy Dr E. Maturi, NOAA), from a polar orbiter (top right; AMSR2 microwave radiometer, descending passes for one day, from http://images.remss.com/amsr/amsr2_data_daily.html), in situ measurements (bottom left; from http://www.star.nesdis.noaa.gov/sod/sst/iquam/v2/ for the month of May, 2014).

Data & Information Creation							
	Swath satellite only (L2)	**Gridded satellite SST Product (L3)**	**Gridded, gap-free satellite SST Product (L4)**	**Native in situ SST Product**	**Gridded in situ SST Product (L3)**	**Gridded, gap-free in situ SST Product (L4)**	**Gridded, gap-free merged Satellite/ In Situ SST (L4)**
Readiness Level[1]	Mature	Mature	Mature	Mature	Mature	Mature	Mature
Oversight & Coordination	GHRSST	GHRSST	GHRSST	JCOMM ICOADS	UK Met Office, NODC, NCDC, ICOADS	NODC, NCDC, JMA (COBE), NOC	GHRSST, UK Met Office, NCDC, JMA (COBE2), Kaplan (LDEO)
Data Centre/ repository	NOAA NODC, NASA PO.DAAC, CEDA	NOAA NODC, NASA PO.DAAC	NOAA NODC, NASA PO.DAAC	JCOMM, NODC, ICOADS, NCAR	UK Met Office, NODC, NCC, ICOADS, NCAR	NODC, NCDC, Tokyo Climate Centre	NODC, NCDC, UK Met Office, Tokyo Climate Centre
Data Stream delivery and QC…	QC by data providers. NASA JPL PO-DAAC & NODC	QC by data providers. NASA JPL PO-DAAC & NODC	QC by data providers. NASA JPL PO-DAAC & NODC	QC by data providers and ICOADS, & NODC	QC by data providers and NODC, NCDC	QC by data providers and NODC, NCDC, ICOADS	QC by data providers. NASA JPL PO-DAAC & NODC
Derived Products	Sensible and latent turbulent heat and momentum fluxes to the atmosphere. Electromagnetic emission (long-wave fluxes). Upper ocean heat content. Atmospheric reanalysis, ocean reanalysis, coupled reanalysis, weather to decadal forecasts. Height adjusted winds, air temperature and humidity. Satellite-derived air temperature and humidity products. Atmospheric simulations of recent climate. Reconstruction of ocean surface current from passive microwave SST fields.						

Links & References	
Links* (especially regarding Background & Justification)	www.ghrsst.org www.ceos.org/sst
Links for Contributing Networks	www.ghrsst.org www.ceos.org/sst www.jcommops.org http://www.remss.com/ http://gcom-w1.jaxa.jp/index.html http://podaac.jpl.nasa.gov http://icoads.noaa.gov/ http://www.ncdc.noaa.gov/ http://www.nodc.noaa.gov/ http://www.bodc.ac.uk/ http://www.myocean.eu/ http://www.esa-sst-cci.org/ http://www.ceda.ac.uk/
Data References	Many in the published literature, including: Donlon, C. J., and Coauthors, 2007: The Global Ocean Data Assimilation Experiment High-resolution Sea Surface Temperature Pilot Project. *Bulletin of the American Meteorological Society*, **88,** 1197-1213. Donlon, C. J., and Coauthors, 2010: Successes and Challenges for the Modern Sea Surface Temperature Observing System. Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society (Vol. 2), Venice, Italy, 21-25 September 2009, Hall, J., Harrison, D.E. & Stammer, D., Eds., ESA Publication WPP-306, doi: 10.5270/OceanObs09.cwp.24 Kennedy, J. J. (2014), A review of uncertainty in in situ measurements and data sets of sea surface temperature, Reviews of Geophysics, 52, 1–32, doi: 10.1002/2013RG000434. Merchant, C. J., and Coauthors, 2012: A twenty-year independent record of sea surface temperature for climate from Along Track Scanning Radiometers, Journal of Geophysical Research, 117, C12013, doi: 10.1029/2012JC008400. Rayner, N. A., and Coauthors, 2010: Evaluating climate variability and change from modern and historical SST observations, Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society (Vol. 2), Venice, Italy, 21-25 September 2009, Hall, J., Harrison, D.E. & Stammer, D., Eds., ESA Publication WPP-306, doi: 10.5270/OceanObs09.cwp.71

[1] **Framework Processes and Readiness Levels** (from the Framework for Ocean Observing [FOO]).

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Highest Readiness Level	Requirements	Observations	Data & Information
Mature	Measurement validated through peer review, implemented at regional and/or global scales and capable of being sustained.	Following validation of observation via peer review of specifications and documentation, system is in place globally and indefinitely.	Validation of data policy via routinely available and relevant information products.
Pilot	Measurement and sampling strategy verified at sea. Autonomous deployment in an operational environment.	Establishment of international governance mechanism, international commitments, and sustaining components. Maintenance and servicing logistics negotiated.	Data management Practices determined and tested for quality and accuracy throughout the system. Creation of draft data policy.
Concept	Need for information identified and characteristics determined. Feasibility study of measurement strategy and technology.	The system is articulated, capability is documented and tested. Proof of concept validated by a basin scale feasibility test.	Data model is articulated, expert review of interoperability strategy. Verification of model with actual observational unit.
Lowest Readiness Level			

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