The use and impacts of sea surface temperature from passive microwave measurements

Anne O‘Carroll

6/12/2017

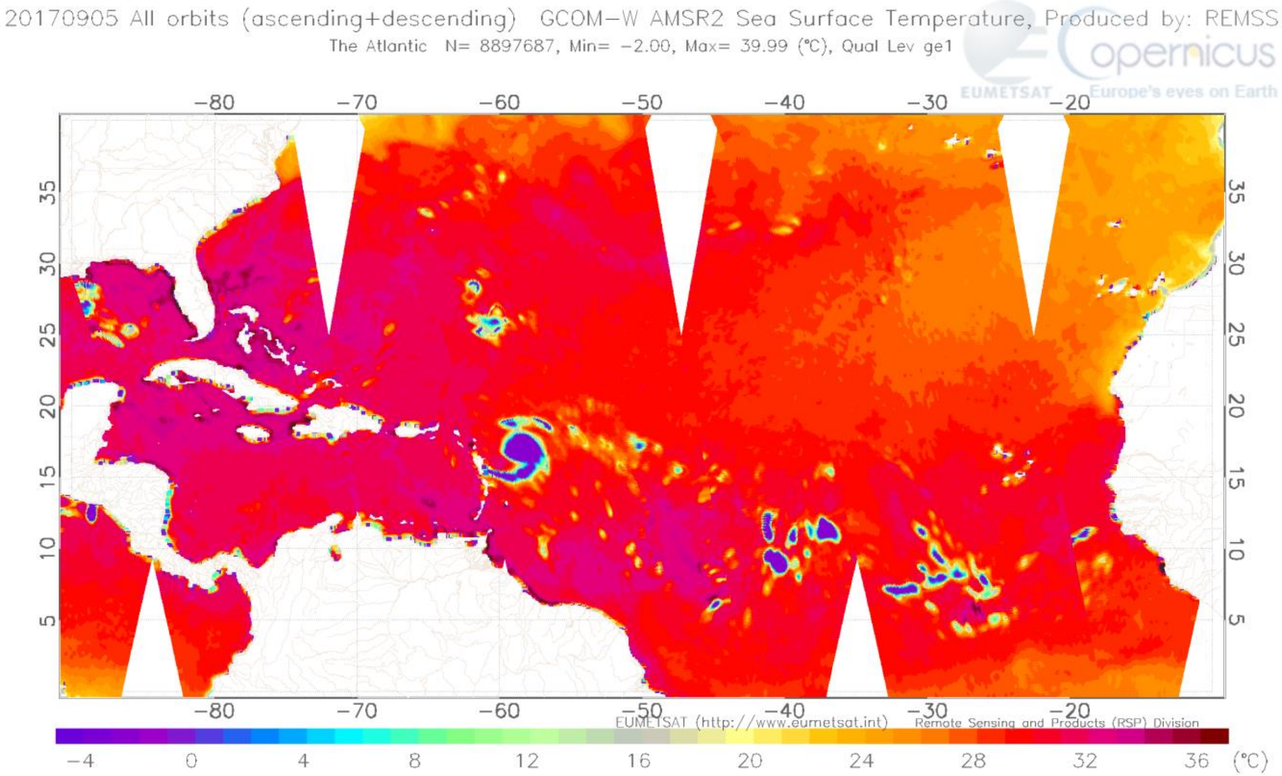
ECMWF workshop on using low frequency passive microwave measurements in research and operational applications

Outline

- Overview of Passive Microwave Radiometer (PMW) for Sea Surface Temperature
- Current and future PMW missions for SST
- Impact of PMW SST on operational analyses and forecasts
- CEOS and CGMS interactions
- Summary

Overview of PMW for SST

E.g. Hurricane Irma



- For global SST need 6-7GHz and 11GHz
- At these wavelengths penetration depth is 2-3mm
- Therefore sub-skin SST, rather than skin SST from IR radiometers

\+

- All weather advantage (not precipitating)
- Combined ability for retrieval of SST plus salinity, wind, rainfall etc useful for operational oceanography

\-

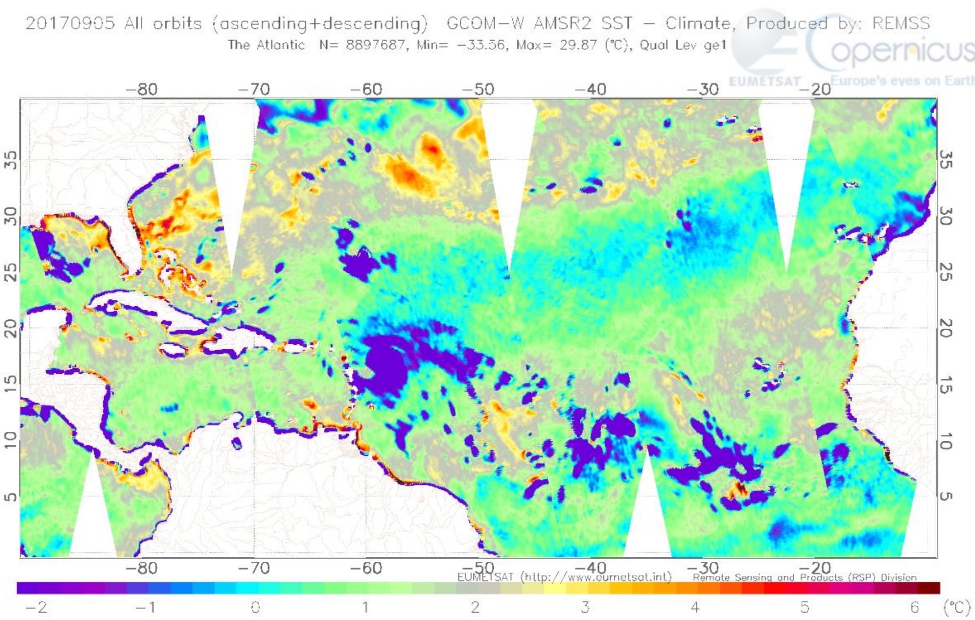
- FOV wider than IR SST due to weak thermal emission at these wavelengths
- Wider antenna needed to achieve better spatial resolution

The use and impacts of sea surface temperature from passive microwave measurements, ECMWF workshop on using low frequency passive microwave measurements in research and operational applications, 4-6 December 2017, Reading

PMW for SST constellation and applications

SST constellation:

- Combination of IR and PMW
- Continuity (and redundancy) of sensors important for both climate and operational applications
- Evolving user needs: better discrimination of sea-ice for both sea-ice and high latitude SST applications; globally higher resolution / improved radiometry



AMSR-2 minus OSTIA climatology SST for Hurricane Irma

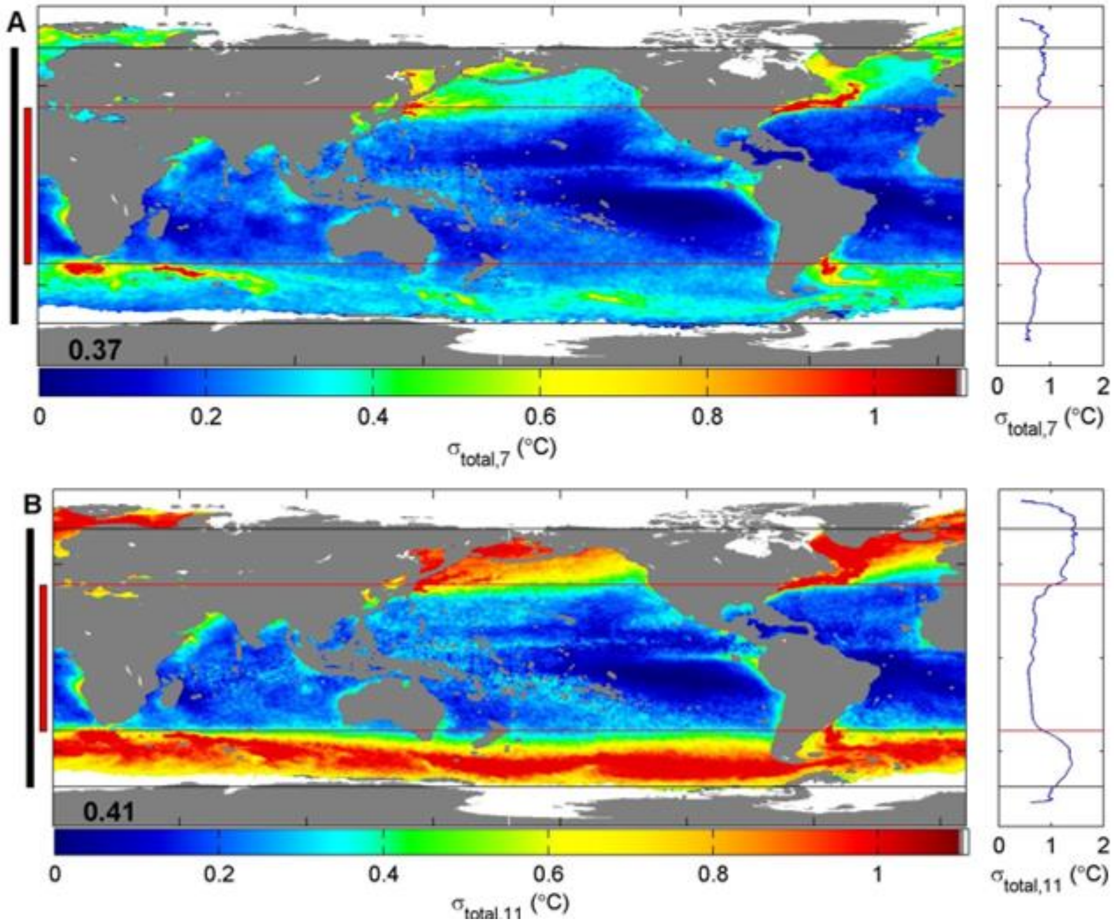
Application examples:

- Operational ocean modelling
- Weather & hurricane / tropical storm forecasting
- Aerosol regions, high latitudes
- SST beneficial for other ocean retrievals

The use and impacts of sea surface temperature from passive microwave measurements, ECMWF workshop on using low frequency passive microwave measurements in research and operational applications, 4-6 December 2017, Reading

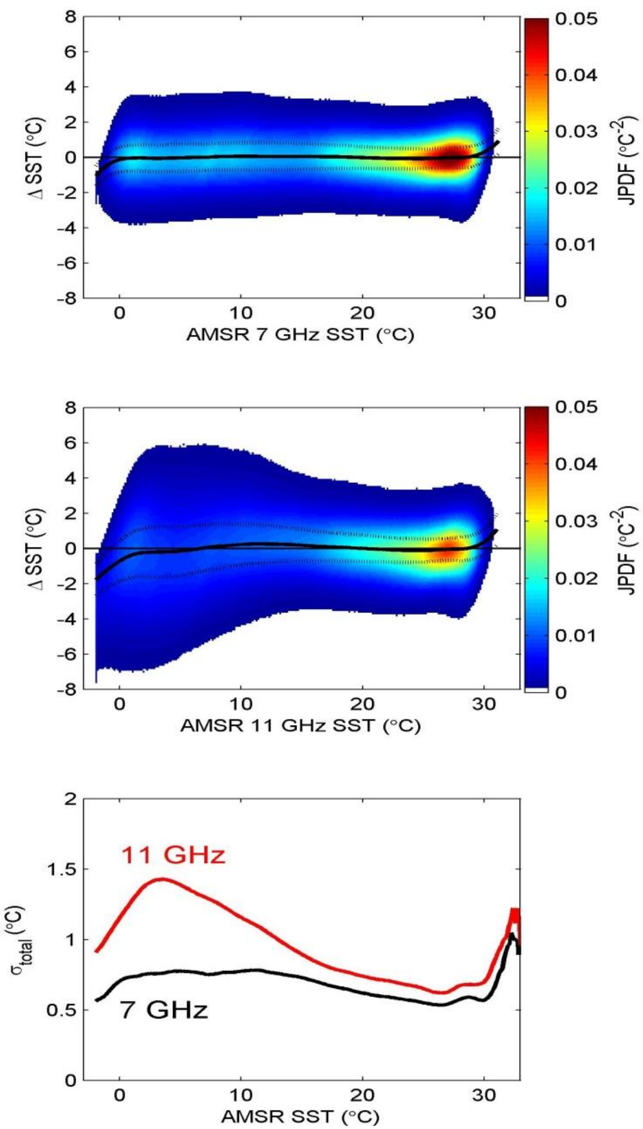
Importance of PMW to SST - example

The benefit to SST retrievals using ~7GHz and ~11GHz channels



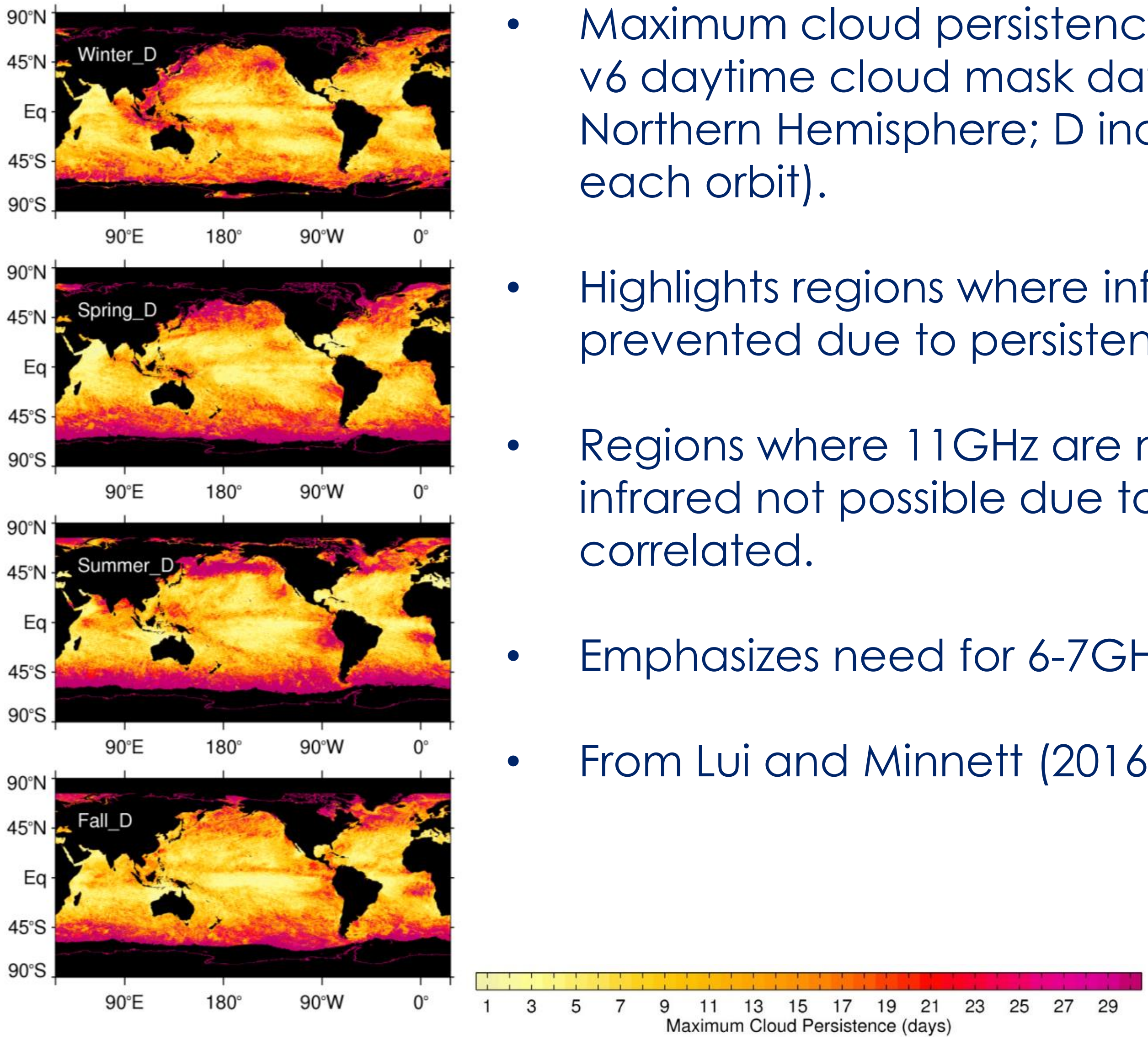
- Standard deviation of differences between AMSR-E and Reynolds SST for top (7GHz AMSR-E SST) and bottom (11GHz AMSR-E SST).
- Map using 11GHz demonstrates significant errors above 40 degree latitude for both hemispheres, due to decreased sensitivity to colder SST at 11 GHz.
- Importance of 6-7GHz channel at high-latitudes.
- From Gentemann et al. (2010).

Importance of 6-7GHz for SST

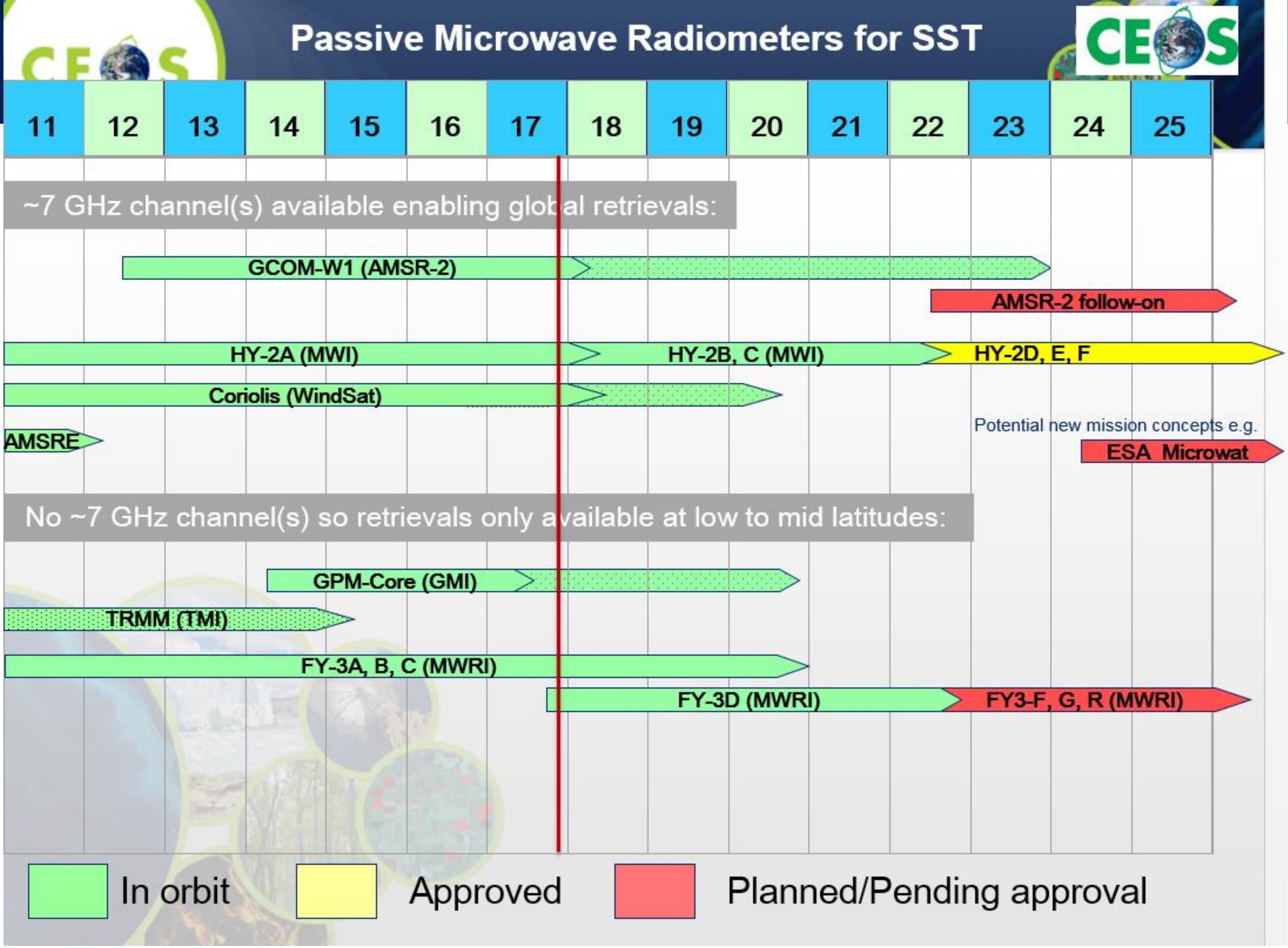


- AMSR-E minus Reynolds SST as a function of 7 GHz SST (top) and 11 GHz SST (bottom).
- Increased differences between the two retrievals at cooler temperatures.
- 7 GHz SST retrieval gives much more stable differences for all temperatures.
- From Gentemann et al. (2010).

Cloud cover limitations



- Maximum cloud persistence (days) from MODIS v6 daytime cloud mask data (seasons relate to Northern Hemisphere; D indicates daytime part of each orbit).
- Highlights regions where infrared SST retrievals are prevented due to persistent cloud cover.
- Regions where 11GHz are not accurate and infrared not possible due to cloud are highly correlated.
- Emphasizes need for 6-7GHz channel.
- From Lui and Minnett (2016).



Passive Microwave Radiometers for SST
CEOS
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
~7 GHz channel(s) available enabling global retrievals:
GCOM-W1 (AMSR-2)
AMSR-2 follow-on
HY-2A (MWI)
HY-2B, C (MWI)
HY-2D, E, F
Coriolis (WindSat)
AMSRE
Potential new mission concepts e.g.
ESA Microwat
No ~7 GHz channel(s) so retrievals only available at low to mid latitudes:
GPM-Core (GMI)
TRMM (TMI)
FY-3A, B, C (MWRI)
FY-3D (MWRI)
FY3-F, G, R (MWRI)
In orbit
Approved
Planned/Pending approval

List of Current and Future Passive Microwave Radiometer Missions for SST Observation

Compiled by M. Kachi, JAXA

Global Change Observation Mission – Water (GCOM-W)

- Phase: OPERATION
- Developer:
  - JAXA (Japan)
- Launch: 17 May, 2012
- Instrument(s):
  - Advanced Microwave Scanning Radiometer 2 (AMSR2)
- Orbit: Sun-synchronous, 700km
- Local Time Ascending Node (ATAN): 13:30

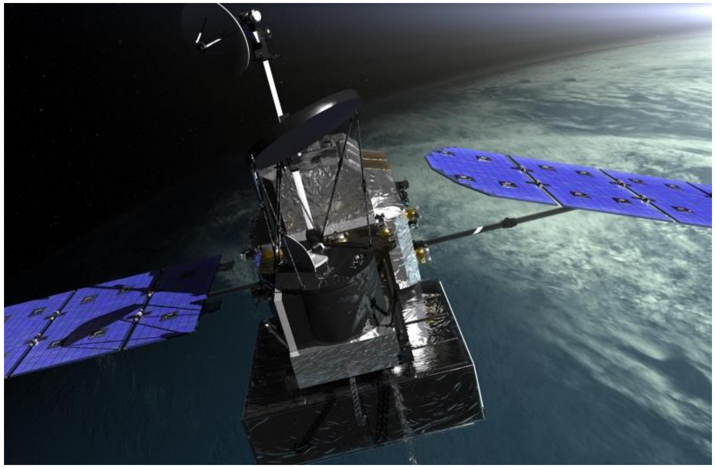
Image by JAXA

AMSR2 Specification	
Antenna size [m]	2.0
Swath width [km]	1600
Channel number	16
Frequency [GHz]	6.925-89.0
Resolution at 6GHz [km]	35x62
Resolution at 10GHz [km]	24x42

GPM Core Observatory

- Phase: OPERATION
- Developer:
  - NASA (US) (GMI, platform)
  - JAXA (Japan) (DPR)
- Launch: 27 February, 2014
- Instrument(s):
  - GPM Microwave Imager (GMI)
  - Dual-frequency Precipitation Radar (DPR)
- Orbit: Non-Sun-synchronous, 402.5km
- Local Time Ascending Node (ATAN): N/A

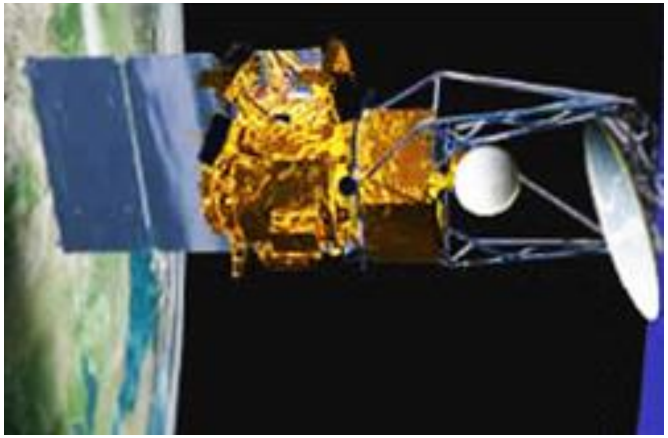
Image by NASA



GMI Specification	
Antenna size [m]	1.2
Swath width [km]	885
Channel number	13
Frequency [GHz]	10.65-183.3
Resolution at 6GHz [km]	N/A
Resolution at 10GHz [km]	19x32

Coriolis

- Phase: OPERATION
- Developer:
  - DoD (US)
- Launch: 6 January, 2003
- Instrument(s):
  - Windsat (Wind Microwave Radiometer)
  - Solar Mass Ejection Imager (SMEI)
- Orbit: Sun-synchronous, 840km
- Local Time Ascending Node (ATAN): 18:00



Windsat Specification	
Antenna size [m]	1.8
Swath width [km]	1000
Channel number	22
Frequency [GHz]	6.8-37
Resolution at 6GHz [km]	40x60
Resolution at 10GHz [km]	25x38

HaiYang-2A (HY-2A)

- Phase: OPERATION
- Developer:
  - SOA/NSOAS (China)
- Launch: 15 August, 2011
- Instrument(s):
  - Microwave Radiometer Imager (MWRI)
  - Radar Altimeter (RA)
  - Ku-band Rotational Fan-beam Scatterometer (SCAT), etc.
- Orbit: Sun-synchronous, 973km
- Local Time Ascending Node (ATAN): 18:00

Image by NSOAS

MWRI Specification	
Antenna size [m]	1.0
Swath width [km]	1600
Channel number	9
Frequency [GHz]	6.6-37
Resolution at 6GHz [km]	100x75
Resolution at 10GHz [km]	75x50

HaiYang-2B (HY-2B)

- Phase: *APPROVED*
- Developer:
  - SOA/NSOAS (China)
- Launch: 2018
- Instrument(s):
  - Microwave Radiometer Imager (MWRI)
  - Radar Altimeter (RA)
  - Ku-band Rotational Fan-beam Scatterometer (SCAT), etc.
- Orbit: Sun-synchronous, 970km
- Local Time Ascending Node (ATAN): 18:00

Image by NSOAS

MWRI Specification	
Antenna size [m]	1.0
Swath width [km]	1600
Channel number	9
Frequency [GHz]	6.9-37
Resolution at 6GHz [km]	150x90
Resolution at 10GHz [km]	110x70

Earth incidence angle of HY-2A MWRI is 47.7 deg, while the Earth incidence angle of HY-2B MWRI is 53 deg.

FengYun-3B (FY-3B)

- Phase: OPERATION
- Developer:
  - CMA (China)
- Launch: November 5, 2010
- Instrument(s):
  - Microwave Radiometer Imager (MWRI)
  - Microwave Temperature Sounder (MWTS)
  - Microwave Humidity Sounder (MWHS), etc.
- Orbit: Sun-synchronous, 836.4km
- Local Time Ascending Node (ATAN): 13:40

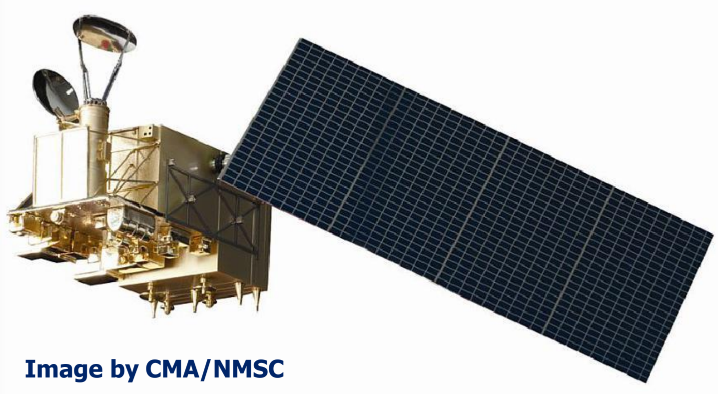


Image by CMA/NMSC

MWRI Specification	
Antenna size [m]	0.98x 0.90
Swath width [km]	1430
Channel number	10
Frequency [GHz]	10.65 -89
Resolution at 6GHz [km]	N/A
Resolution at 10GHz [km]	51x8 5

FengYun-3C (FY-3C)

- Phase: OPERATION
- Developer:
  - CMA (China)
- Launch: 23 September, 2013
- Instrument(s):
  - Microwave Radiometer Imager (MWRI)
  - Microwave Temperature Sounder (MWTS)
  - Microwave Humidity Sounder (MWHS), etc.
- Orbit: Sun-synchronous, 836.4km
- Local Time Ascending Node (ATAN): 22:00

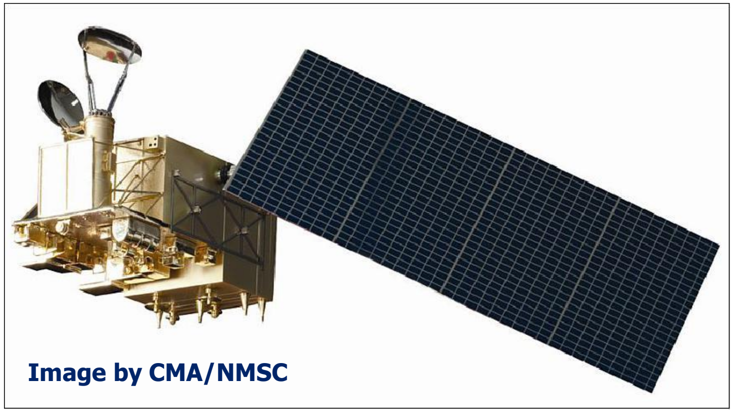
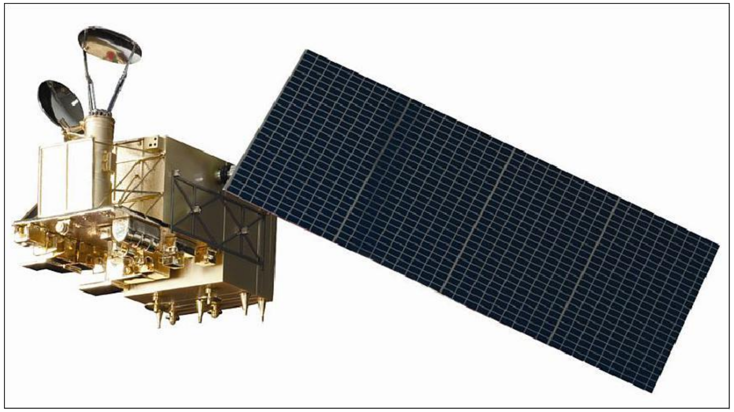


Image by CMA/NMSC

MWRI Specification	
Antenna size [m]	0.98x 0.90
Swath width [km]	1430
Channel number	10
Frequency [GHz]	10.65 -89
Resolution at 6GHz [km]	N/A
Resolution at 10GHz [km]	51x8 5

FengYun-3D (FY-3D)

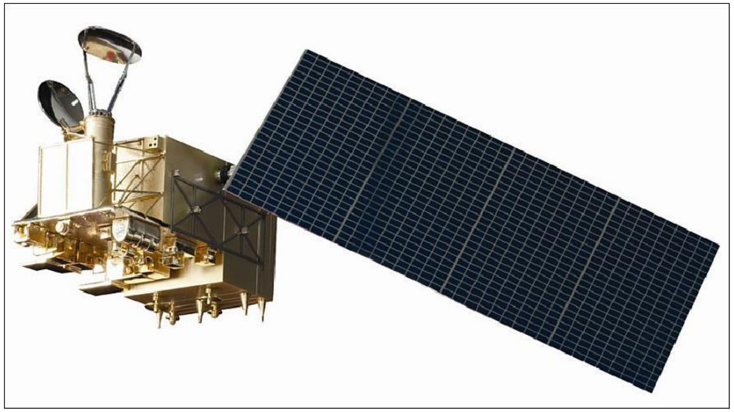
- Phase: Commissioning
- Developer:
  - CMA (China)
- Launch: 15 November, 2017
- Instrument(s):
  - Microwave Radiometer Imager (MWRI)
  - Microwave Temperature Sounder (MWTS)
  - Microwave Humidity Sounder (MWHS), etc.
- Orbit: Sun-synchronous, 836.4km
- Local Time Ascending Node (ATAN): 01:30 AM



MWRI Specification	
Antenna size [m]	0.98x 0.90
Swath width [km]	1430
Channel number	10
Frequency [GHz]	10.65 -89
Resolution at 6GHz [km]	N/A
Resolution at 10GHz [km]	51x8 5

FengYun-3F (FY-3F)

- Phase: *PLANNED*
- Developer:
  - CMA (China)
- Launch: 2019
- Instrument(s):
  - Microwave Radiometer Imager (MWRI)
  - Microwave Temperature Sounder (MWTS)
  - Microwave Humidity Sounder (MWHS), etc.
- Orbit: Sun-synchronous, 836.4km
- Local Time Ascending Node (ATAN): PM



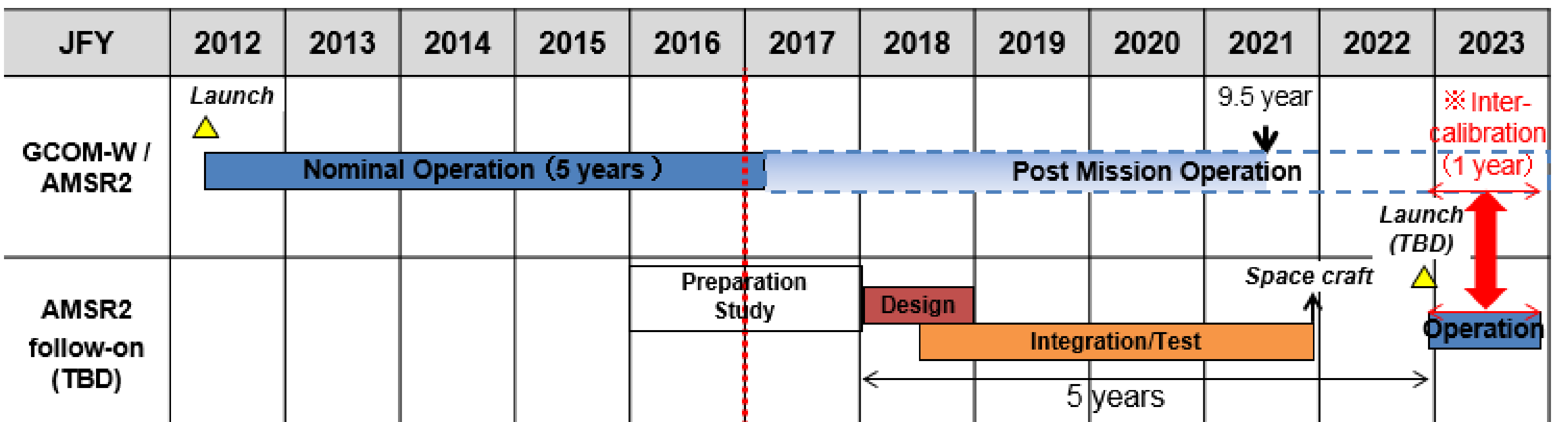
MWRI Specification	
Antenna size [m]	0.98x 0.90
Swath width [km]	1430
Channel number	10
Frequency [GHz]	10.65 -89
Resolution at 6GHz [km]	N/A
Resolution at 10GHz [km]	51x8 5

Upcoming and potential Passive Microwave Radiometer Missions for SST Observation

Update from JAXA (to GHRSST / SST-VC)

AMSR2 follow-on mission discussion

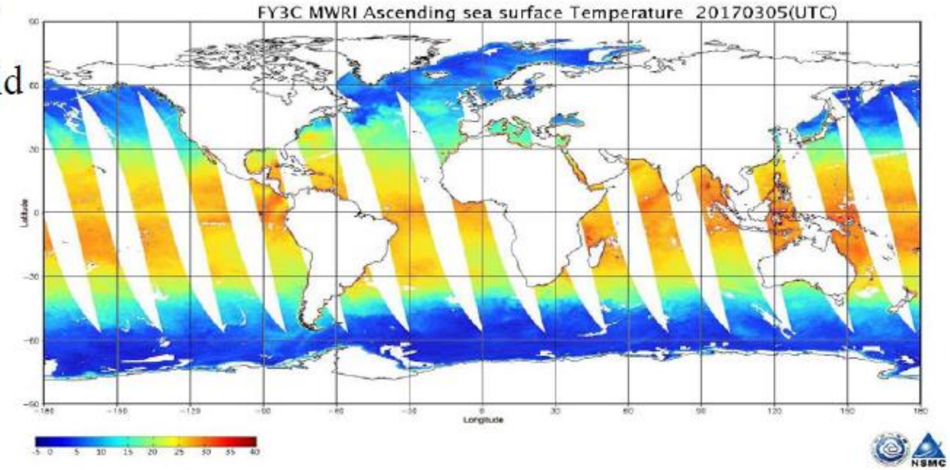
- Continuity is the highest priority of users
  - ✓ Small budget is accepted to conduct research on hosted payload capability of AMSR2 follow-on onto GOSAT-3 in JFY2017 in corresponding to revision of the roadmap for the Basic Plan on Space Policy. JAXA discussed with scientists on scientific synergies between two missions.
  - ✓ There is a high risk of gap between AMSR2 and the follow-on, even though development of AMSR2 follow-on will start from JFY2018.
  - ✓ AMSR2 operation will be continued as long as it can survive.

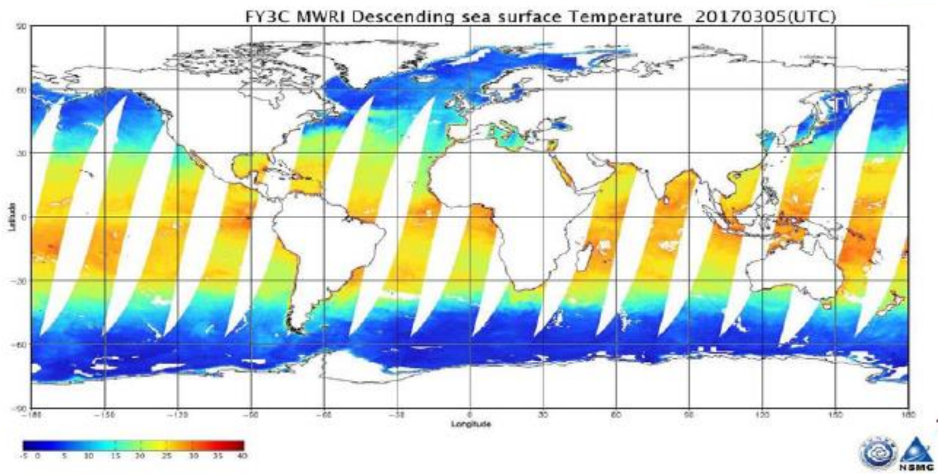


Update from CMA (to GHRSST / SST-VC)

LEO MW SST- FY3C/MWRI daily SST(research)

- derived from orbit SST
- 25km regular lat/lon grid





17

Improvements needed on accuracy of FY-SST from PMW

CMA and GHRSST establishing more cooperation in SST operational product validation and data blending

Potential new European Copernicus PMW capability

- Copernicus passive microwave radiometer, potential capability in planning;
- Copernicus Imaging Microwave Radiometer (CIMR);
- Meeting evolving user needs;
- Higher spatial resolution expected, improved radiometry;
- EUMETSAT to operate and produce marine products including Sea Surface Temperature;
- All tbd with European Commission.

Water Cycle Observation Mission (WCOM)

- Mission dedicate to global water cycle parameters;
- Soil moisture, ocean surface salinity, snow water equivalent and frozen / thaw; also surface temperature;
- Includes 3 microwave payloads (IMI, DPS, PMI);
- Polarimetric Microwave Imager (PMI): C-band to W-band
  - Includes 6.8GHz for global retrievals
- Swath width ~1000km, mean spatial resolution ~4-50km
- Implementation expected 2016-2020

Dong, X., J. Shi, S. Zhang, H. Liu, Z. Wang, D. Zhu, L. Zuo, C. Chen, W. Chen, Preliminary design of water cycle observation mission (WCOM)

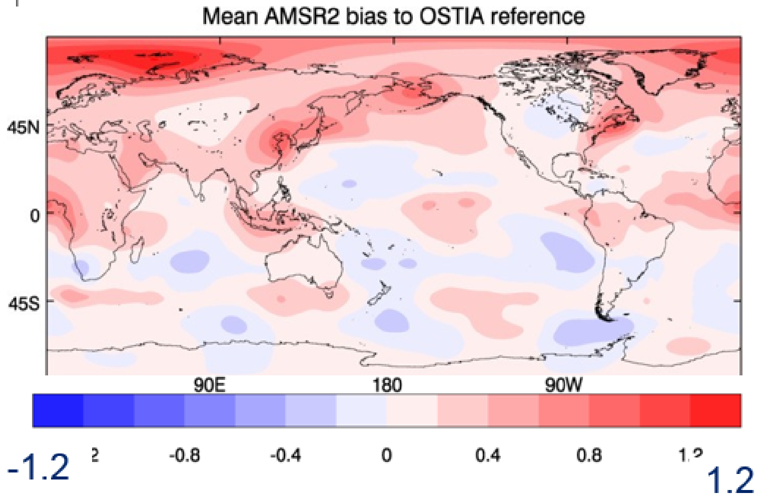
Impact of PMW Sea Surface Temperature on operational analyses and forecasts

Compiled by S. Good, Met Office, on behalf of the Group for High Resolution Sea Surface Temperature

Impact on OSTIA analyses (E. Fiedler, Met Office)

Met Office

Mean AMSR2 bias to OSTIA reference, Jan 2016 (K)



Microwave useful as independent dataset for verification. Agreement with VIIRS (infra-red; not shown) on differences to reference data in Arctic suggests MetOp AVHRR reference data too cold. Useful comparison as in situ observations for validation in Arctic not available.

- Large positive “bias” for REMSS AMSR2 compared OSTIA reference data (in situ and high quality subset of MetOp AVHRR) off the coast of Africa (see plot).
- Likely linked to Saharan aerosols.
- Microwave AMSR2 instrument not sensitive to aerosols, unlike reference AVHRR.
- Microwave dataset provides additional information which is erroneously “corrected” out by comparison to reference infra-red dataset.

Impact on OSTIA analyses (2) (E. Fiedler, Met Office)

Met Office

Argo minus OSTIA for January 2016, global statistics

Experiment	RMS diff to Argo (K)
Control	0.50
+ AMSR2	0.44
+ VIIRS	0.44
+ AMSR2, VIIRS	0.42

•Assimilation of REMSS AMSR2 L2P microwave data improves OSTIA analysis RMS difference to Argo over including ACSPO VIIRS L3U alone (though not necessarily due to specific properties of microwave SST data).

•AMSR2 provides more observations than other datasets at very high latitudes, important for analysis as observations sparse here.

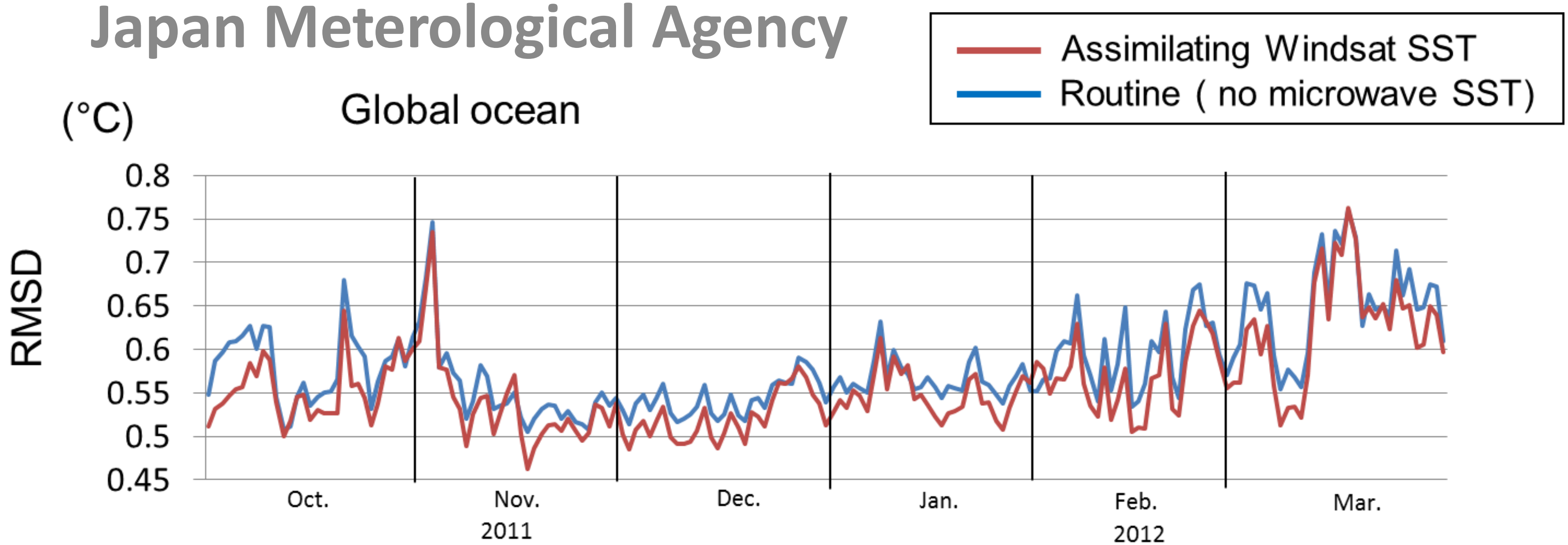
•Microwave data is likely to improve SST feature resolution in regions of persistent cloud cover (future work to verify this)

Impact of Windsat SST on MGDSST analysis (1)

- Any microwave SST data had not been used in the operational MGDSST analysis from Oct. 2011 to Jan. 2013 due to AMSR-E instrument failure.
- Impact test was conducted by assimilating Windsat SST on MGDSST analysis for the period from Oct. 2011 to Mar. 2012, and each analysis was compared with buoy SST.
- Assimilating Windsat SST reduced the RMSD in the global ocean.

Toshiyuki Sakurai

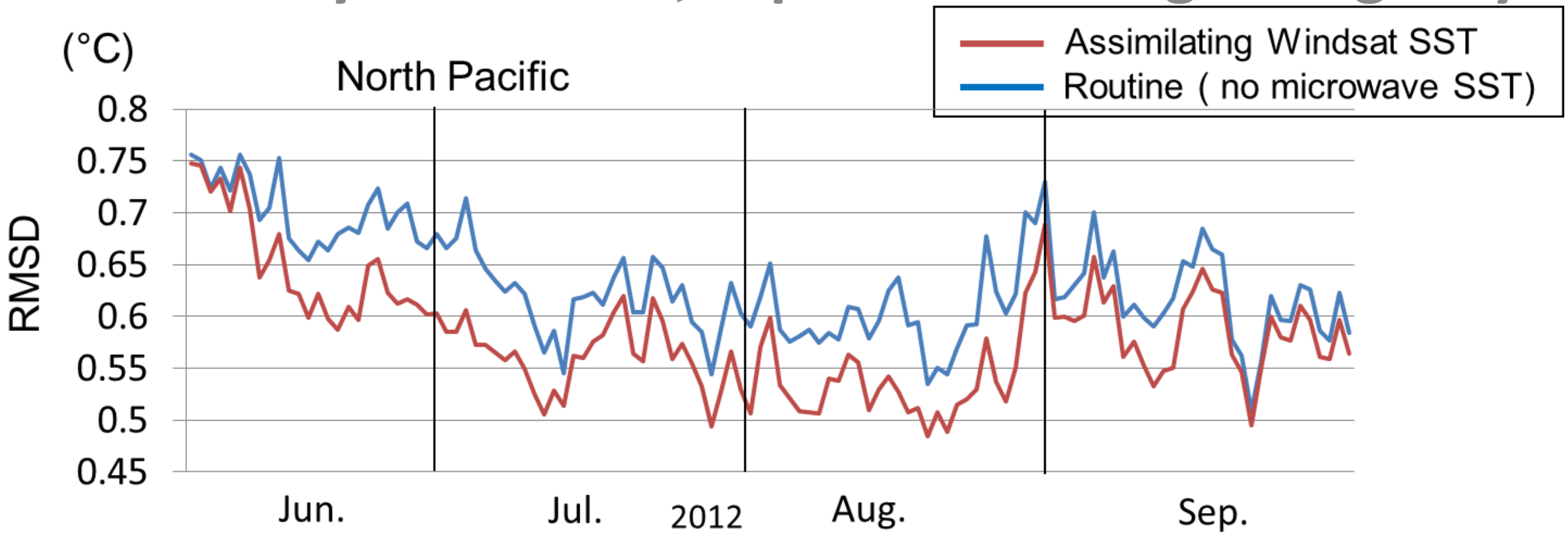
Japan Meterological Agency



Impact of Windsat SST on MGDSST analysis (2)

- Another impact test of Windsat SST was conducted for the period from Jun. to Sep. 2012.
- Assimilating Windsat SST significantly reduced the RMSD in the North Pacific by about 0.05°C. This is because availabilities of SST by IR sensors become very low in the summer North Pacific due to persistent cloud cover, while the microwave sensor has the ability to retrieve SST in cloud-cover region.

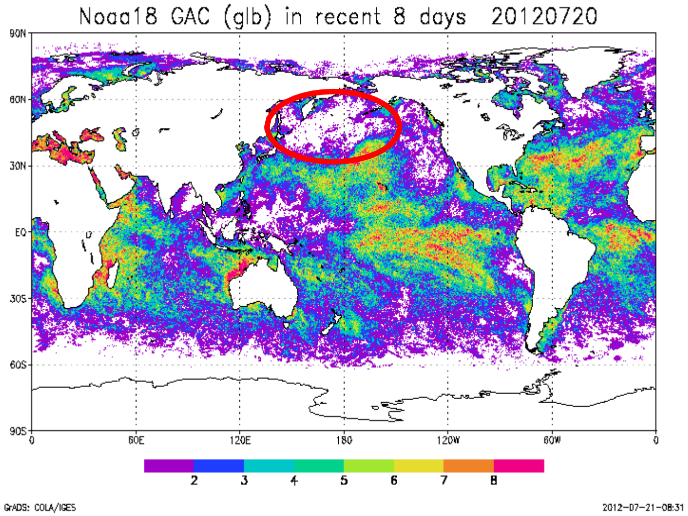
Toshiyuki Sakurai, Japan Meterological Agency



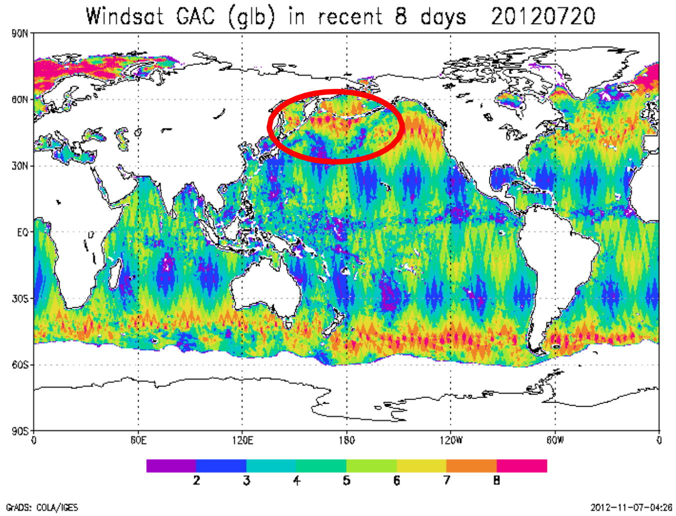
Persistent cloud cover (3)　Toshiyuki Sakurai, JMA

Number of satellite's observations for 8 days from 13 to 20 Jul. 2012 (number is counted for daily averaged value)

AVHRR/NOAA18

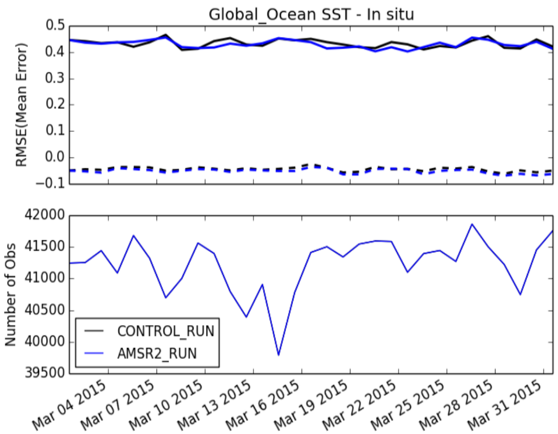


Windsat

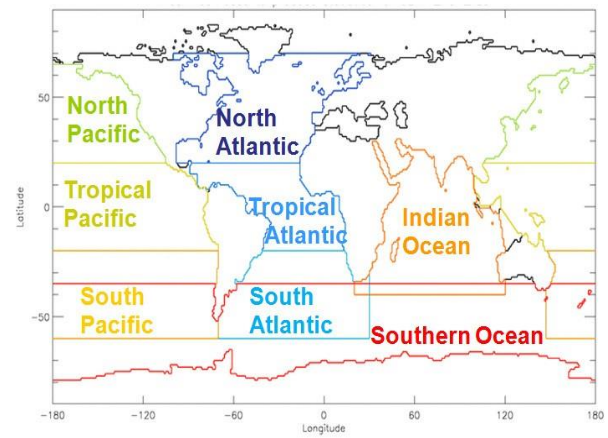


Availabilities of SST by IR sensors are lower than those by MW sensors in the summer North Pacific where persistent cloud cover exists.

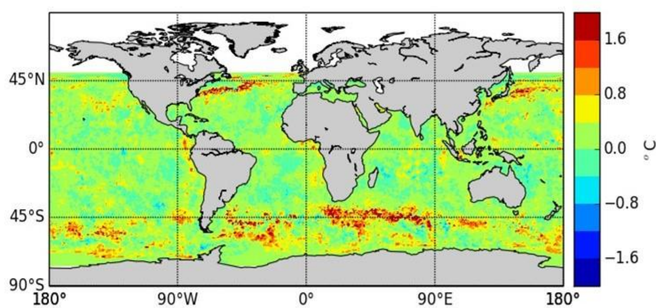
Impact on Met Office ocean forecasts (I. Ascione, Met Office



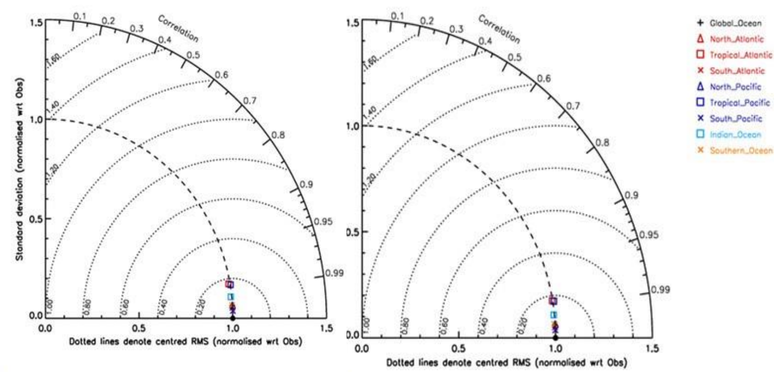
Global Ocean SST errors in the Control experiment (black) and in AMSR2 experiment (blue)



Results were averaged over sub- regions of the global



SST field difference between the AMSR2 experiment and the Control experiment at the end of the simulation period.



Control Experiment (Without AMSR2) **with AMSR2**

Summary of Global FOAM trials (I. Ascione, Met Office)

- Modelling experiments were carried out to test AMSR2-JAXA SST data in FOAM system
- The global average results show that differences between experiments were minimal
- Error statistics show that all experiments performed well
- Results at the end of the simulation period show that the largest SST differences between the experiments were found at high latitudes

Impact of Windsat on the Bureau of Meteorology ocean model OceanMAPS2

Pavel Sakov Bureau of Meteorology

Assimilating WindSat microwave SST (in addition to existing AVHRR infrared SST) resulted in significant reduction in SST forecast innovation RMSD in the ABoM regional 0.1° resolution ocean model during 2012

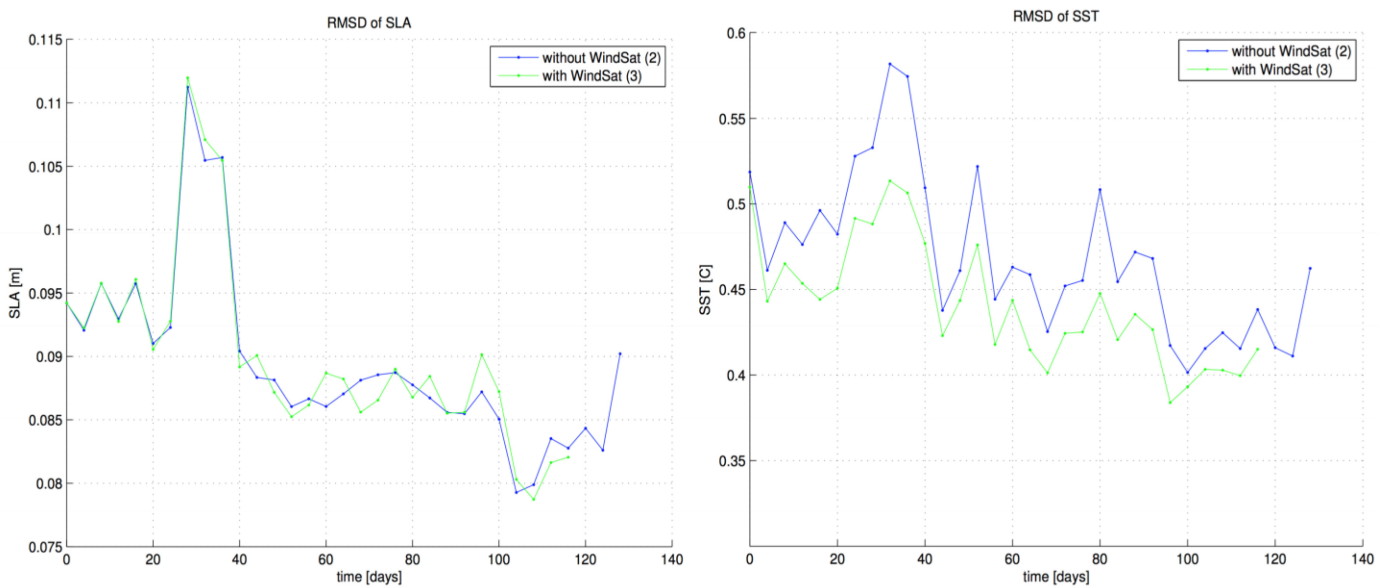
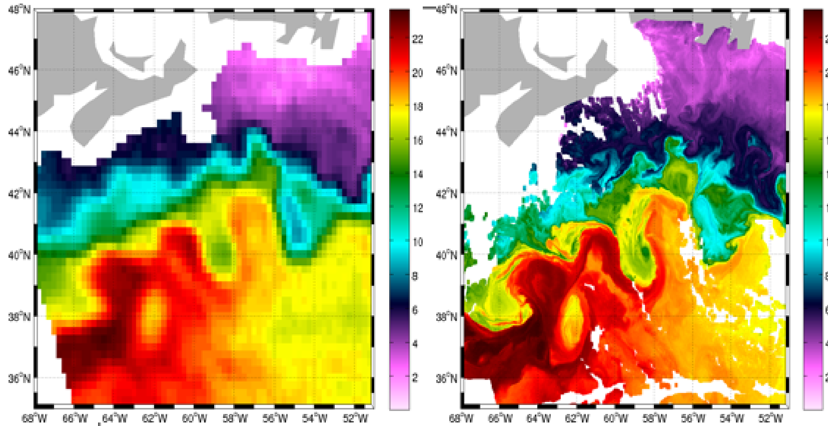


Figure 1: Forecast innovation RMSD of OceanMAPS v2 without and with SST observations from WindSat.

Australian Government
Bureau of Meteorology

High resolution SST fields from microwave observations (E. Autret, Ifremer)



Microwave (MW) and infrared (IR) from SSTs AMSR-E and MODIS

High Resolution SST fields from microwave observations

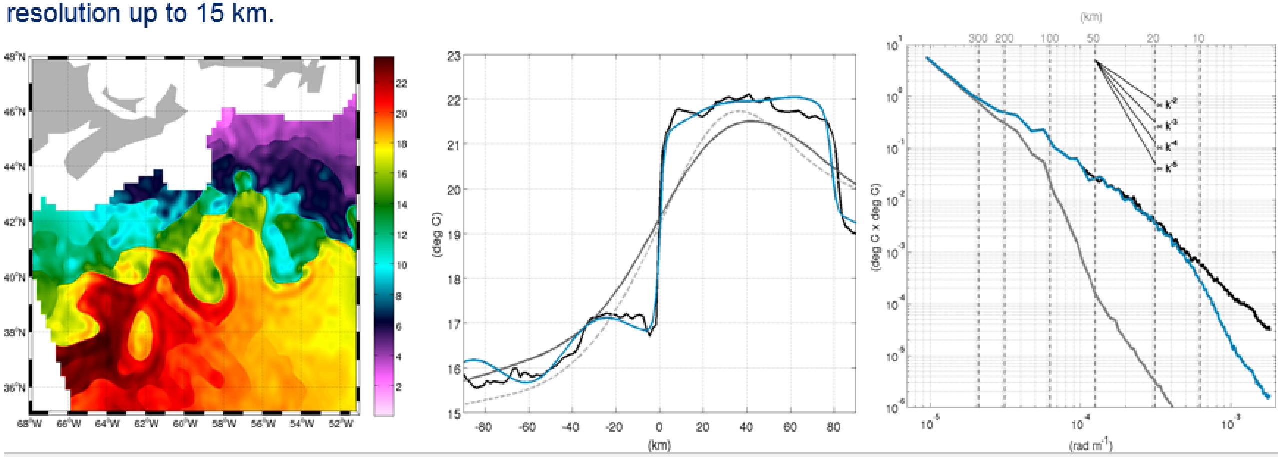
Small scales and SST fronts make a significant contribution to the horizontal and vertical transport in the upper oceanic layers :

Interactions of sharp SST gradients and the marine atmospherique boundary layer and deeper atmosphere
Major contribution in methods aiming to retrieve horizontal velocities from surface data

We are provided with :

Low resolution (LR, ~ 60 km) SST observations with a global and quasi daily coverage
Discontinuous high resolution (HR, ~ 1-5 km) SST observations that are valid only for clear-sky conditions (high energetic regions can be poorly sampled)

Enhanced resolution of global and daily SST fields can be achieved with Eulerian or Lagrangian techniques. The results presented here are produced from microwave observations from gradient transformation (Autret 2014, Autret 2016 in prep.). The Eulerian technique relies on the characterization of high resolution SST fields (~ IR products res.) with respect to low resolution (~ MW products res.). The method allows for reconstructing the major SST fronts from microwave observations and improve the spatial resolution up to 15 km.



Left : Reconstructed HR SST field from the AMSR-E data ; Middle : example of SST front from AMSR-E (grey), MODIS (black) and the reconstructed field (blue). Right : SST spectra from AMSR-E (grey), MODIS (black) and the reconstructed field (blue).

Summary of use of PMW for SST

- Use of Passive Microwave Radiometers (PMW) for SST retrievals is an essential component of global constellation of SST sensors.
- Provides temperature of ocean under clouds, not possible from infrared sensors, albeit with poorer spatial resolution. Important in high-latitude regions and in areas of extensive and persistent cloud cover or in case of a large volcanic event.
- Impact studies of SST analyses / ocean forecasts show PMW also needed for:
  - Verification of SST analyses (and inter-comparisons) at the poles.
  - Aerosol regions (robust to IR sensitivity displayed in these regions).
  - Improves feature definition (e.g. fronts) esp. where persistent cloud.
  - Impact studies show improvement in RMSD (e.g. 0.02K global to 0.05K regional). Particularly important at high latitudes.
  - In addition retrievals of Ocean Surface Salinity Measurements give better performance when using SST analyses including PMW data (e.g. Meissner et al, TGRS-2016-00278)

Recent CEOS / CGMS interactions

CEOS SST-VC

Recent CEOS / CGMS interactions

- SIT-31, April 2016: Passive Microwave Radiometer constellation for SST
  - Uncertain future for PMW SSTs, especially at high latitudes where the PMW SSTs provide valuable through-cloud data in the region where the climate is changing most rapidly.
  - The current outlook means there is a high risk of a gap, particularly for SSTs using the ~7GHz channel.
- CGMS-44, June 2016: Passive Microwave Radiometer constellation for Sea Surface Temperature
  - Progress has been made regarding 'reference' dual-view SST data (Sentinel-3 SLSTR); geostationary SST over full Indian Ocean; increased participation of agencies with SST capability to GHRSST and the SST-VC.
  - There is a risk to the current and continued PMW constellation for SST and a need for a redundant capability of PMW with ~7 GHz. These concerns are now heightened with no confirmed continuity of plans for AMSR-2 available.
  - Operational availability of PMW data from HY-2 and in the future from Meteor.
- SIT TW, September 2016: Importance of PMW constellation for SST and impacts
- SIT TW, September 2017: PMW continuity

Recent summary and requests made to CEOS

Currently there are still risks and gaps identified in constellation, therefore continuity and redundancy of PMW for SST continues to be sought.

- Given the current risk to the current and continued PMW constellation for SST and the need for a redundant capability of PMW with ~7 GHz, ***CEOS is requested to continue to coordinate and encourage its agencies to ensure the continuation of the existing capability and to facilitate the coordination of agencies to ensure continuity and redundancy of PMW for SST.***

- These data are particularly important for SST analyses and ocean models at high latitudes, aerosol regions, persistent cloudy regions, feature definition and overall contribute to an improvement in ocean forecast skill.

- AMSR-2 follow-on is not yet approved, but study on possible payload to the GOSAT-3 satellite is being conducted in JFY 2017. The SST-VC note that approval of this mission would give the greatest opportunity for continuation of PMW for SST applications.

- Significant progress is being made with CMA on cooperation with SST, together with the SST-VC and GHRSST

PMW constellation status in the last year

For Global retrievals including high latitudes:

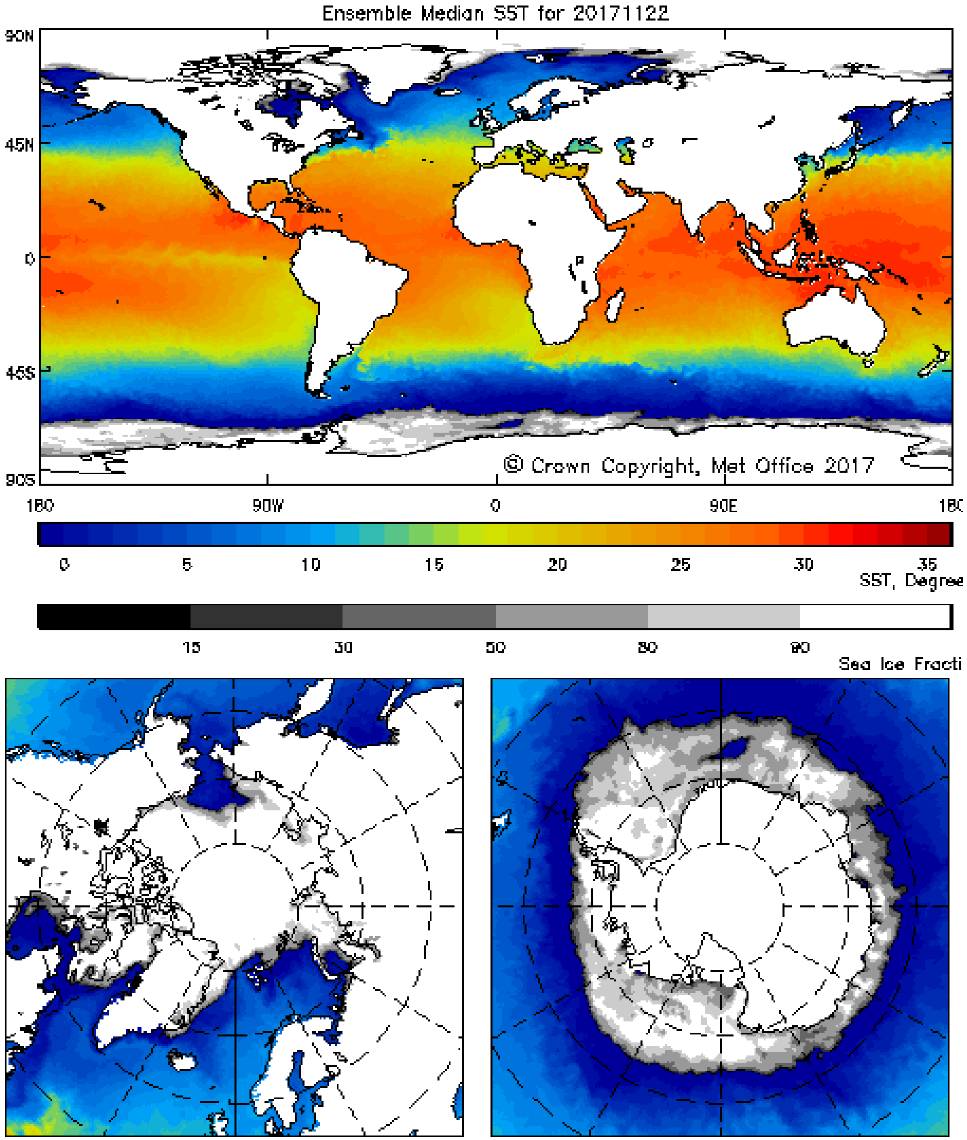
- AMSR-2 follow-on is not approved at the moment (also essential for continuity).
- HY-2 series continuing, but operational access and GHRSST data specification not yet established. GHRSST discussions continued with NSOAS in 2017.
- Coriolis continuing but entering extended mission.
- Potential new European Copernicus PMW mission in planning to meet evolving user needs.

For low / mid-latitude retrievals:

- FY-3 series continuing. CMA welcomed as new members of SST-VC. Working towards GHRSST specification. Discussions begun at the GHRSST science team meeting, June 2017.
- GPM-Core continuing but entering extended mission.

Summary

- PMW capability including 6-7GHz channel essential for global SST constellation
- Currently still risks and gaps identified in constellation although continuation of missions and potential new capability in planning



Thank you and any questions?

Anne.Ocarroll@eumetsat.int