Operational systems for SST products

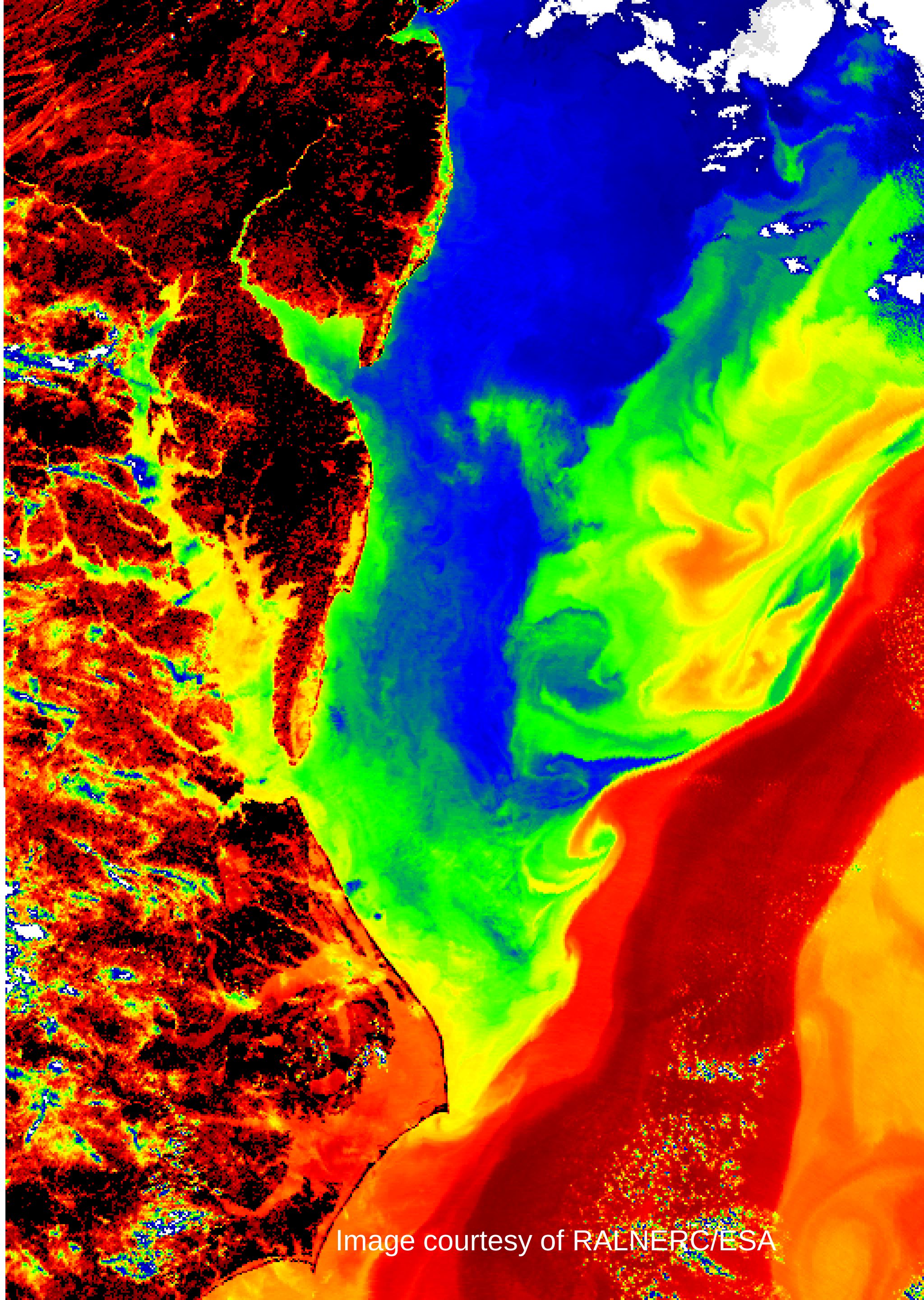
Prof. Chris Merchant
University of Reading
UK

Classic Images from ATSR

The Gulf Stream

ATSR-2 Image, ƛ = 3.7µm

Review the steps to get SST using a physical retrieval



“Meteorological SSTs” – widely used, **operational**

- Routine, automated, internationally integrated system for generating and distributing daily SST maps to users (www.ghrsst.org)
  - Near-real time
  - Data sharing / data access
  - User focussed
  - Standardized for simplicity
  - “L4” (i.e., spatially complete) analyses of multiple sensors

- Numerical weather prediction
- Oceanography (inc. assimilation)
- Shipping
- Fishing
- Military
- Ecological monitoring (e.g., coral watch)
- Extractive industries at sea

Satellite SST for climate

- After a stable, accurate, independent record of SST from satellite
  - to re-assess recent global change
  - to extend the assessment of change into regions where in situ observations are uncomfortably sparse
  - to re-evaluate modes of SST variability & historical reconstructions
  - with higher spatial resolution for new climate models
  - to initialise ocean for seasonal to decadal climate prediction

Requirements for SST CDR

Property	GCOS (2006) statement	CCI survey 2010 (L3 breakthru') http://www.esa-sst-cci.org/
Accuracy	0.25 K	0.02 K, demonstrable on 100 km scales
Stability	0.1 K / decade	0.02 K / decade
Precision	--	0.05 K
Spatial resolution	1 km	0.1^{o} (1 km)
Temporal resolution	3 hourly	Day and night (3 hourly)
Uncertainty information	--	Total uncertainty. Error covariance information.
Quality information	--	Simple: probability of "bad"
SST meaning	--	Skin and depth SSTs required
Independence	--	Preferred by >60%

SYSTEM -- SENSORS

Essentials of Radiometry

We Need to know:

- **What we are looking at (Field of view)**
- **At what wavelengths we are looking (spectral Response)**
- **How much radiant power are we receiving (Radiometric Calibration)**

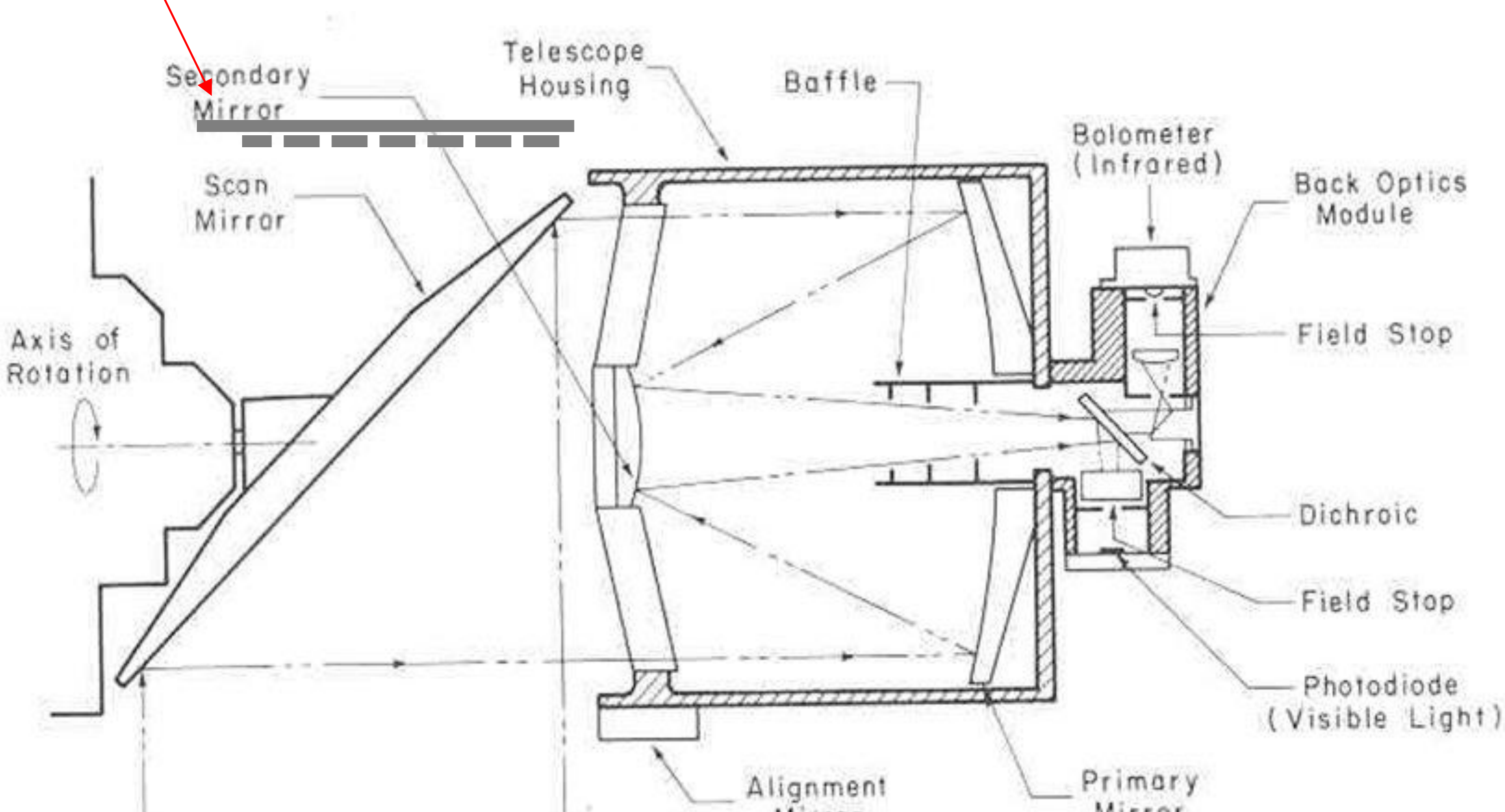
Example of Space-borne Radiometer AVHRR

- **Designed in 1960's**
- **World's first general-access Earth Imager**
- **Telescope to define FoV**
- **Filters to define spectral response of detectors**
- **Single temperature reference target plus a space view to define radiometric standards**

Position of BB ref target

Layout of AVHRR

Simple and Effective!

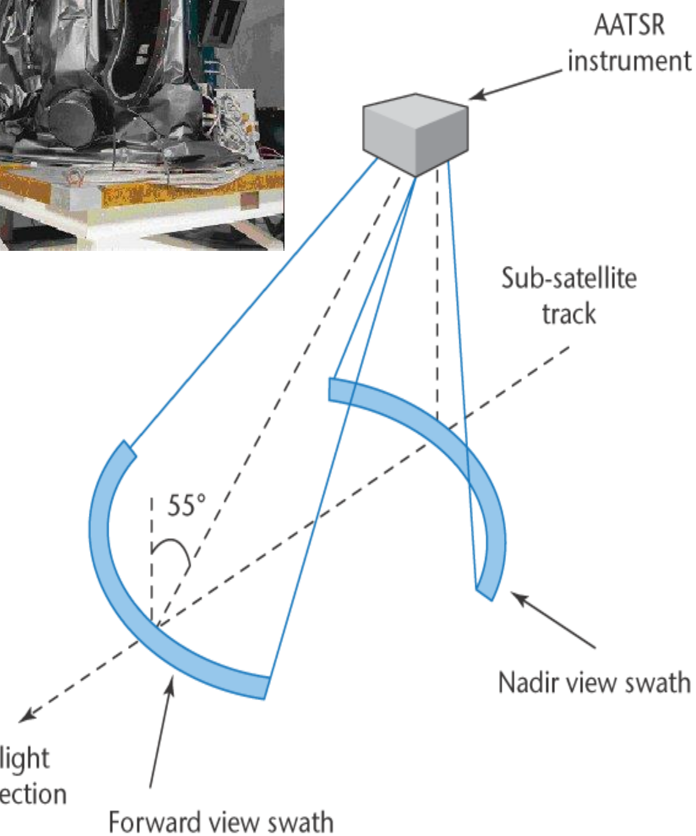


Scan Mirror **Telescope** **Detector**

On-board Calibration

- Need stable, black target(s)
- Stable thermal environment
- Good optical design – no stray light!
- Need to know precise temperature and uniformity of black body target

Along Track Scanning Radiometers

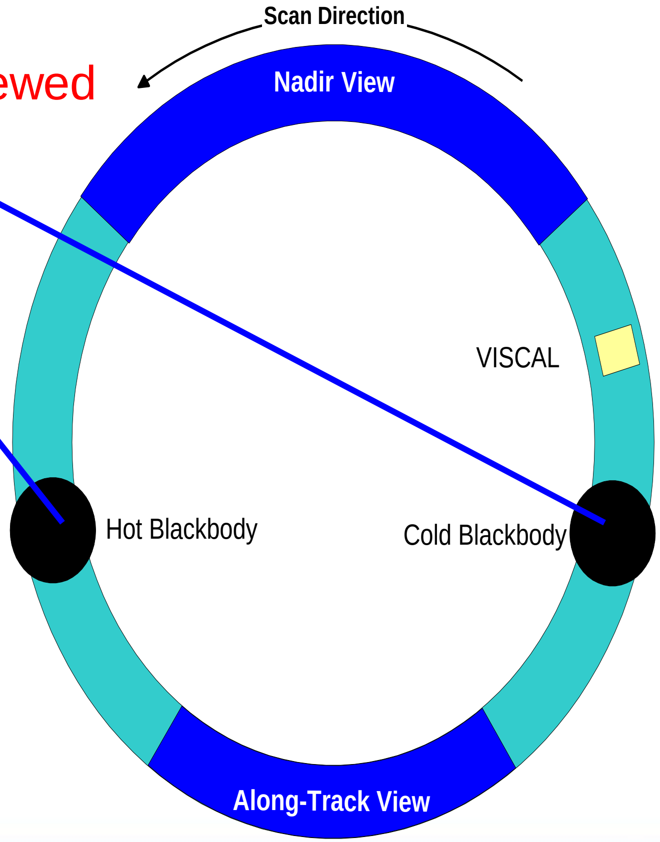


- Series of three
- Dual view
- Two-point high-quality black-body calibration
- Low noise detectors
- Accurately characterized spectral responses

➔ Supports physical approach

ATSR Scan sequence – showing on-board Calibration System

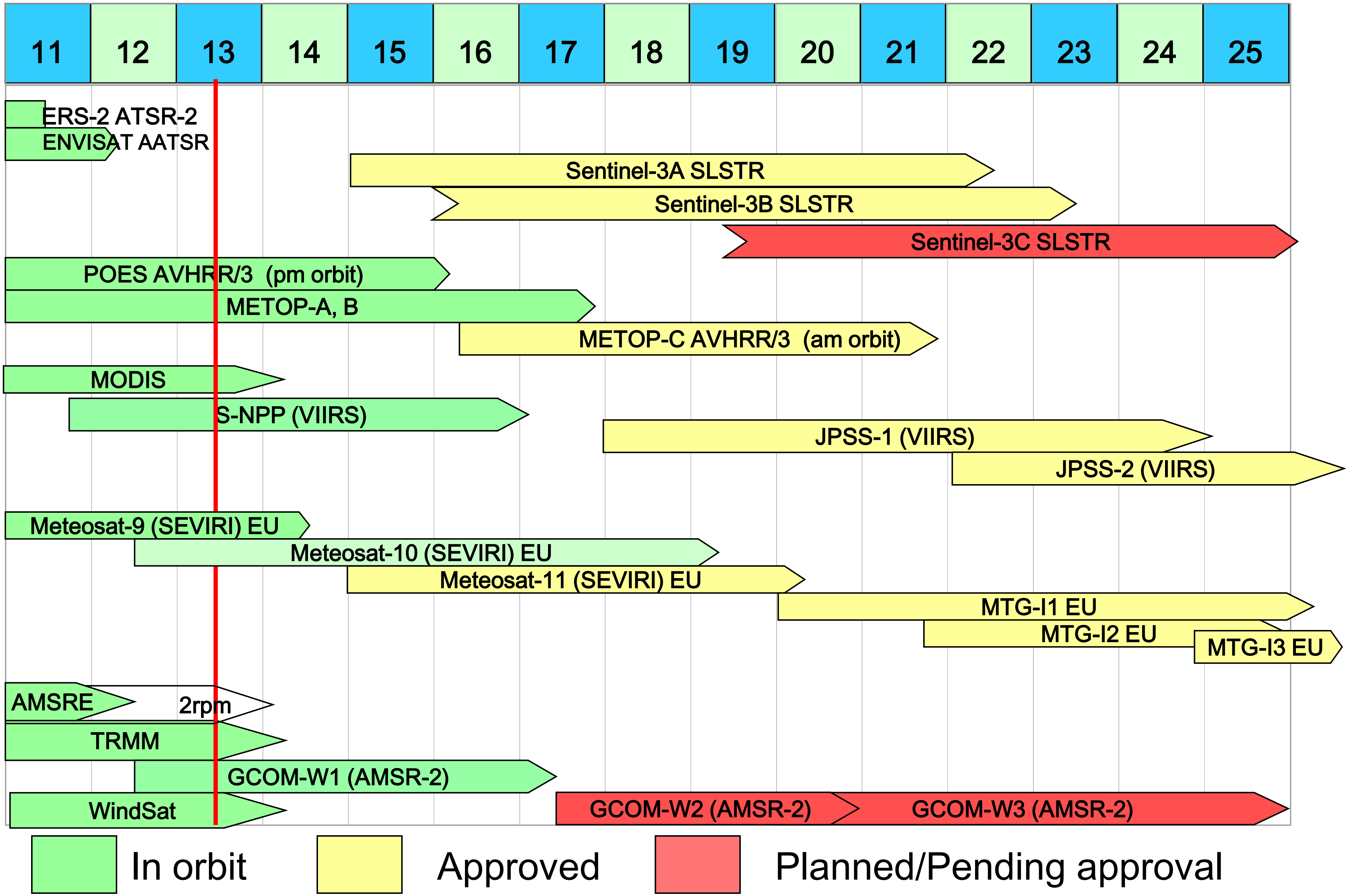
Blackbodies viewed every scan.



An ATSR on-board Black Body

Peering into the Void - How Black is Black?

SYSTEM -- CONSTELLATION



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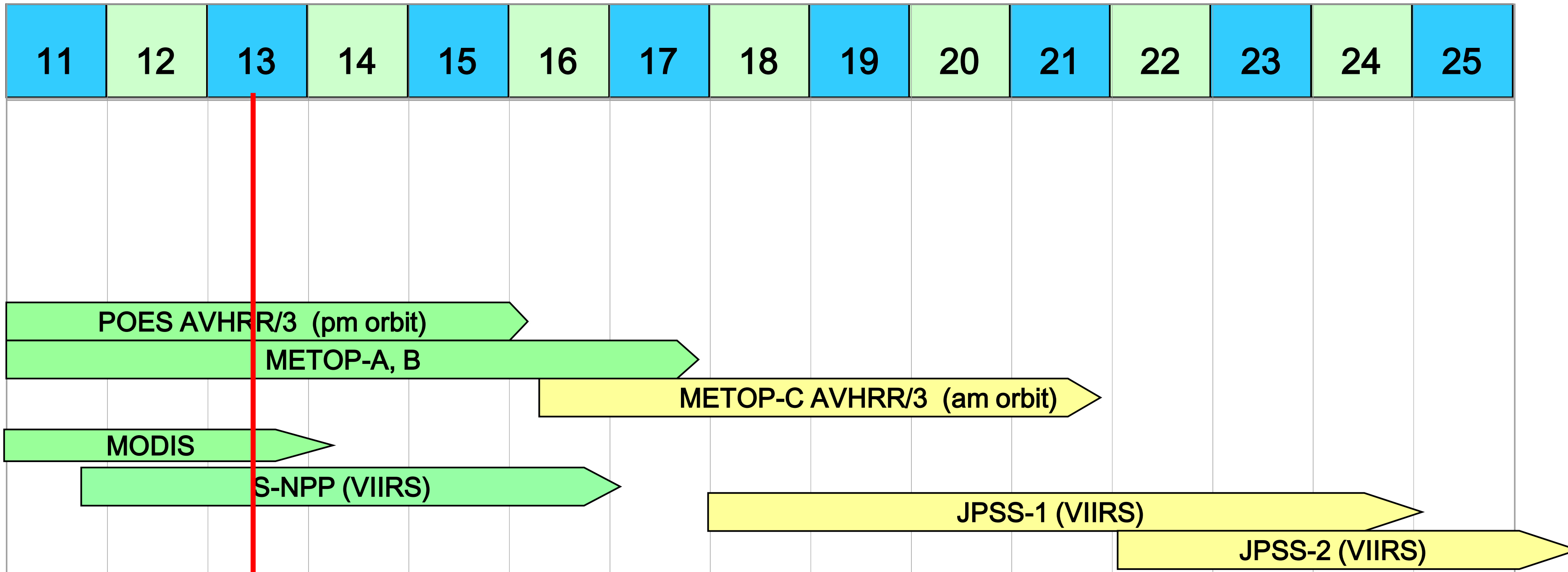
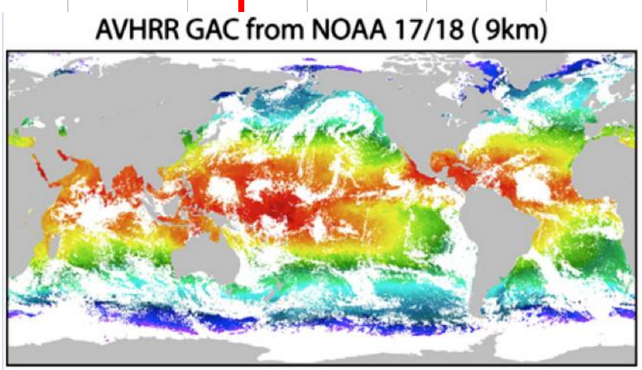
ERS-2 ATSR-2
ENVISAT AATSR
Sentinel-3A SLSTR
Sentinel-3B SLSTR
Sentinel-3C SLSTR
POES AVHRR/3 (pm orbit)
METOP-A, B
METOP-C AVHRR/3 (am orbit)
MODIS
S-NPP (VIIRS)
JPSS-1 (VIIRS)
JPSS-2 (VIIRS)
Meteosat-9 (SEVIRI) EU
Meteosat-10 (SEVIRI) EU
Meteosat-11 (SEVIRI) EU
MTG-I1 EU
MTG-I2 EU
MTG-I3 EU
AMSRE
2rpm
TRMM
GCOM-W1 (AMSR-2)
WindSat
GCOM-W2 (AMSR-2)
GCOM-W3 (AMSR-2)
In orbit
Approved
Planned/Pending approval

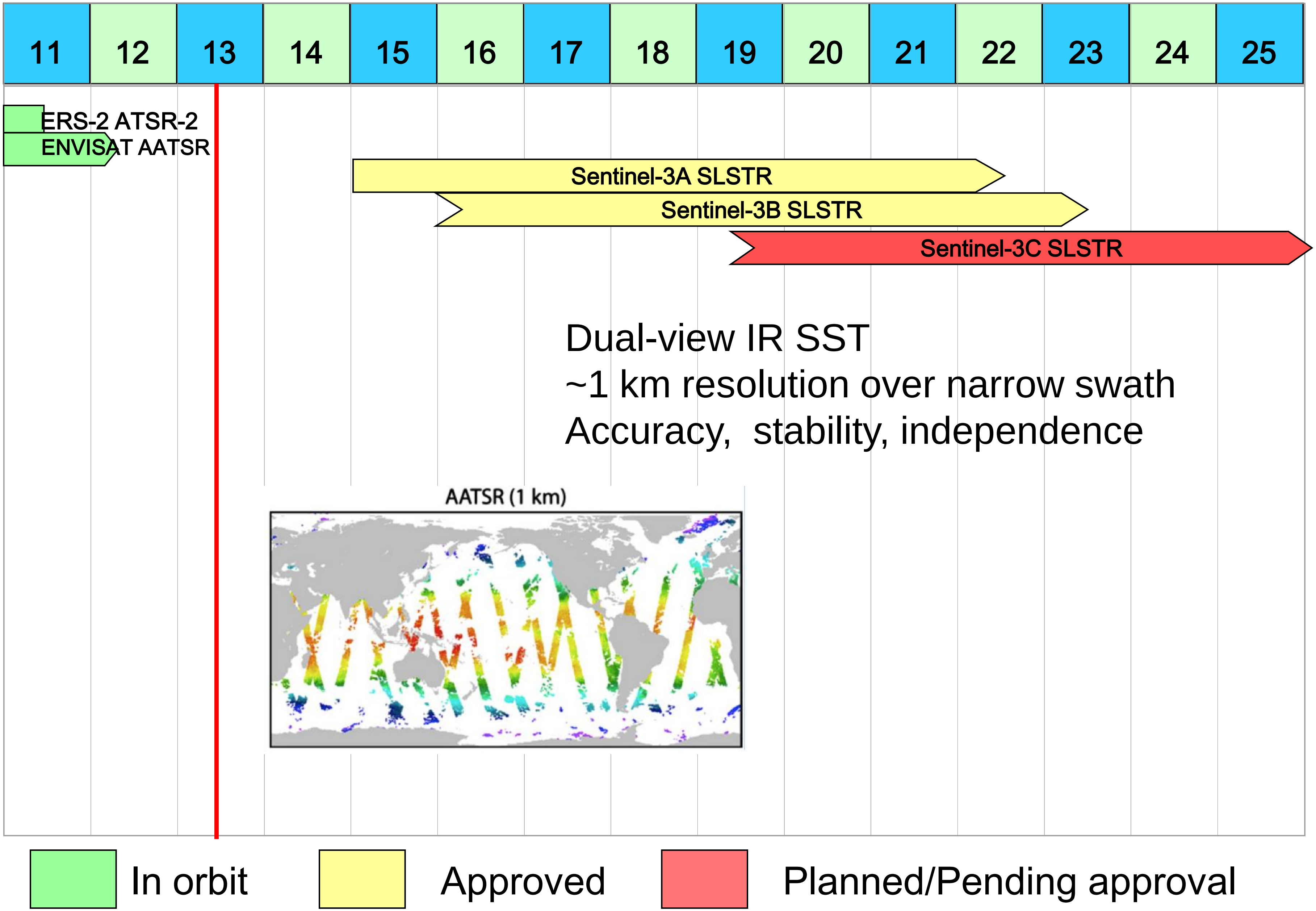




Robinson et al., RSE, 2012

Meteorological polar orbiters
IR SST at ~1 to ~9 km resolution globally
~3000 km swath
Usually at least ‘morning’ and ‘afternoon’
Heritage back to ~1978
Core operational missions

In orbit
Approved
Planned/Pending approval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ERS-2 ATSR-2
ENVISAT AATSR
Sentinel-3A SLSTR
Sentinel-3B SLSTR
Sentinel-3C SLSTR
Dual-view IR SST
~1 km resolution over narrow swath
Accuracy, stability, independence
AATSR (1 km)
In orbit
Approved
Planned/Pending approval

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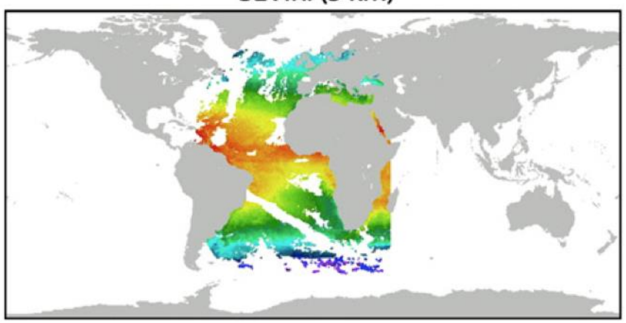
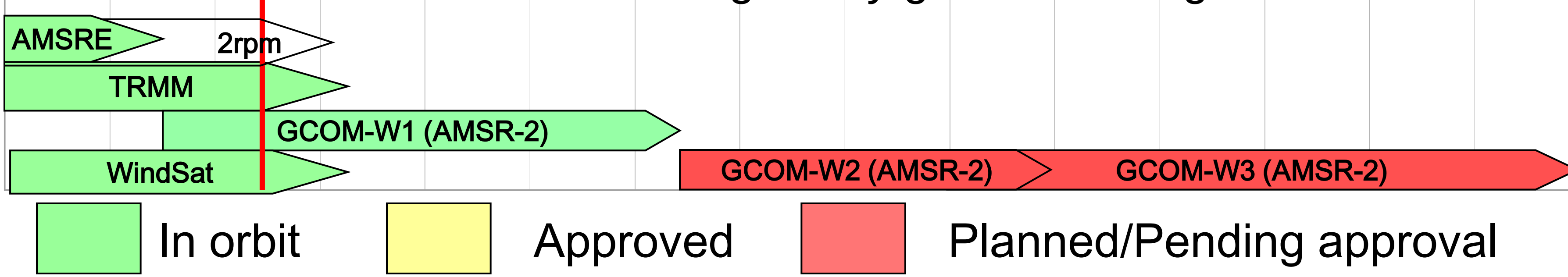


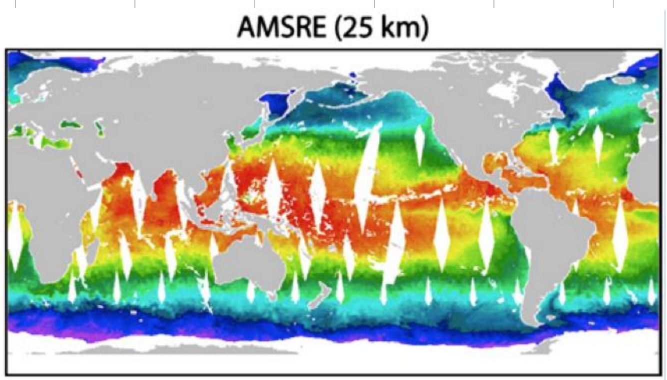
Geostationary platforms
IR SST at ~5 km resolution over disk
3 hourly SST composites are typical
Improve coverage
Observe the SST diurnal cycle

Meteosat-9 (SEVIRI) EU
Meteosat-10 (SEVIRI) EU
Meteosat-11 (SEVIRI) EU
MTG-I1 EU
MTG-I2 EU
MTG-I3 EU

In orbit
Approved
Planned/Pending approval

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

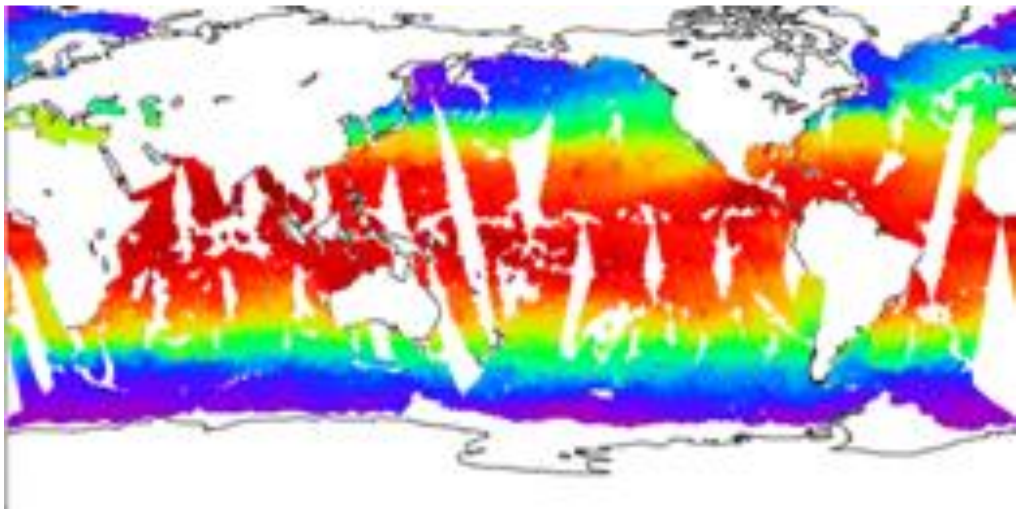


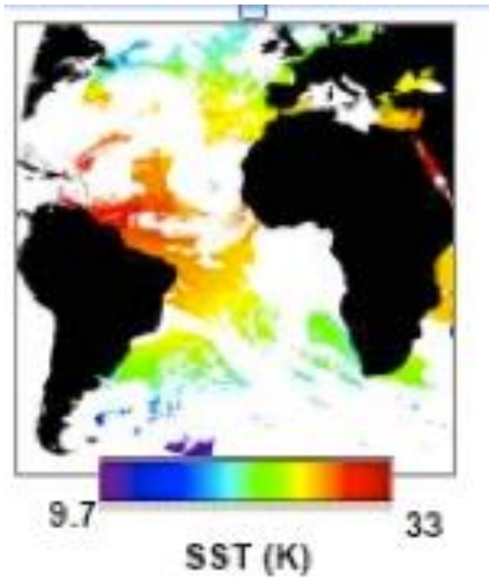


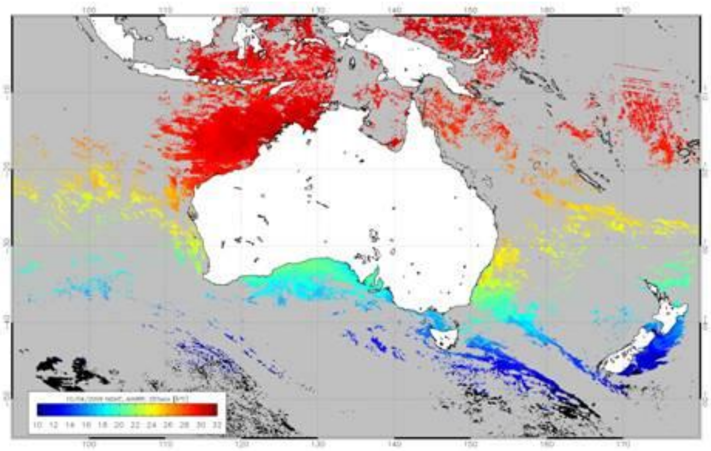
Microwave SST
~50 km resolution, less accurate than IR
No coastal or near-ice SSTs
High daily global coverage

SYSTEM – DATA PROCESSING

“Level 2” (SSTs as obtained)





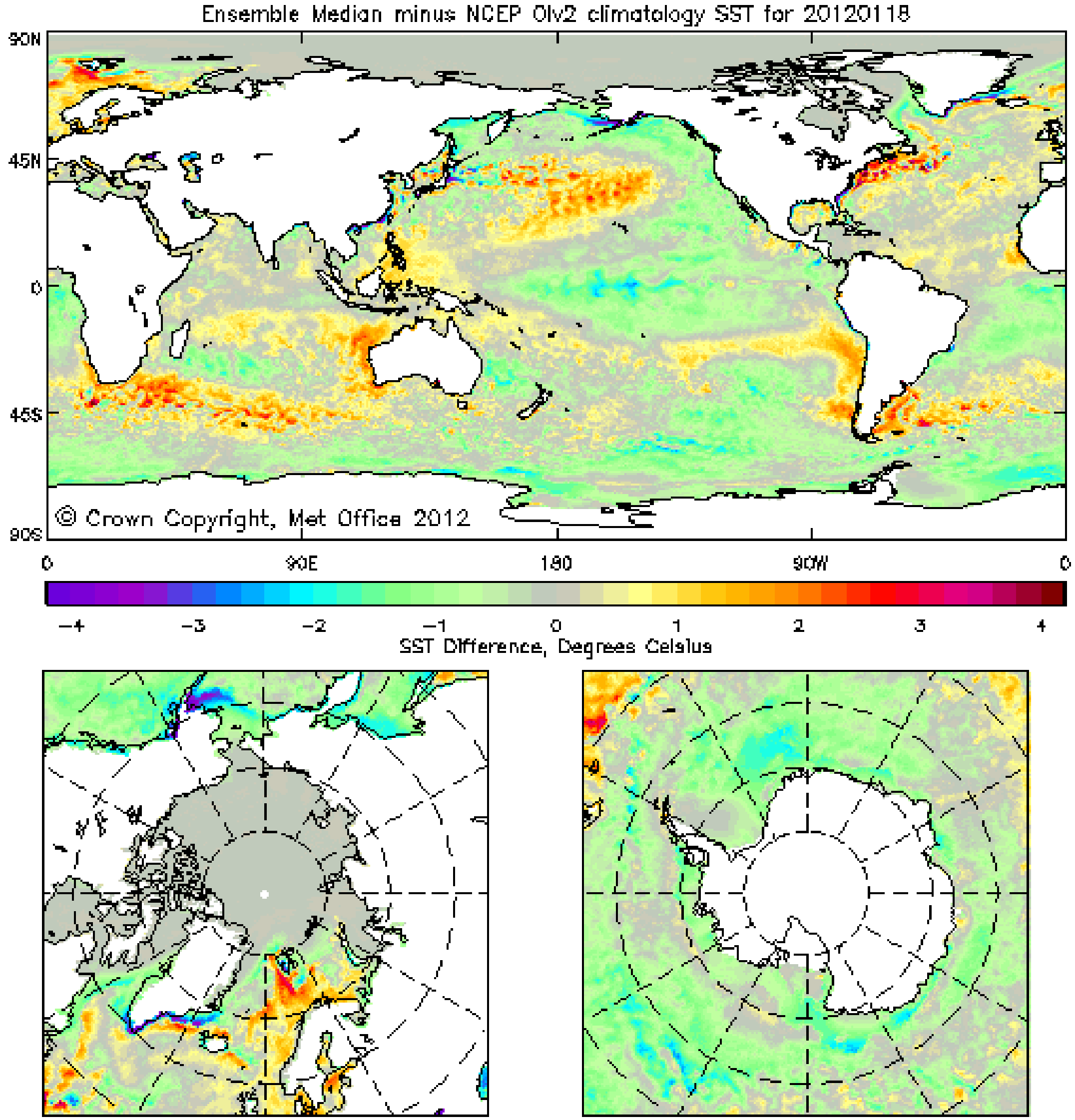


“Level 3” – regularly gridded, perhaps averaged, single sensor

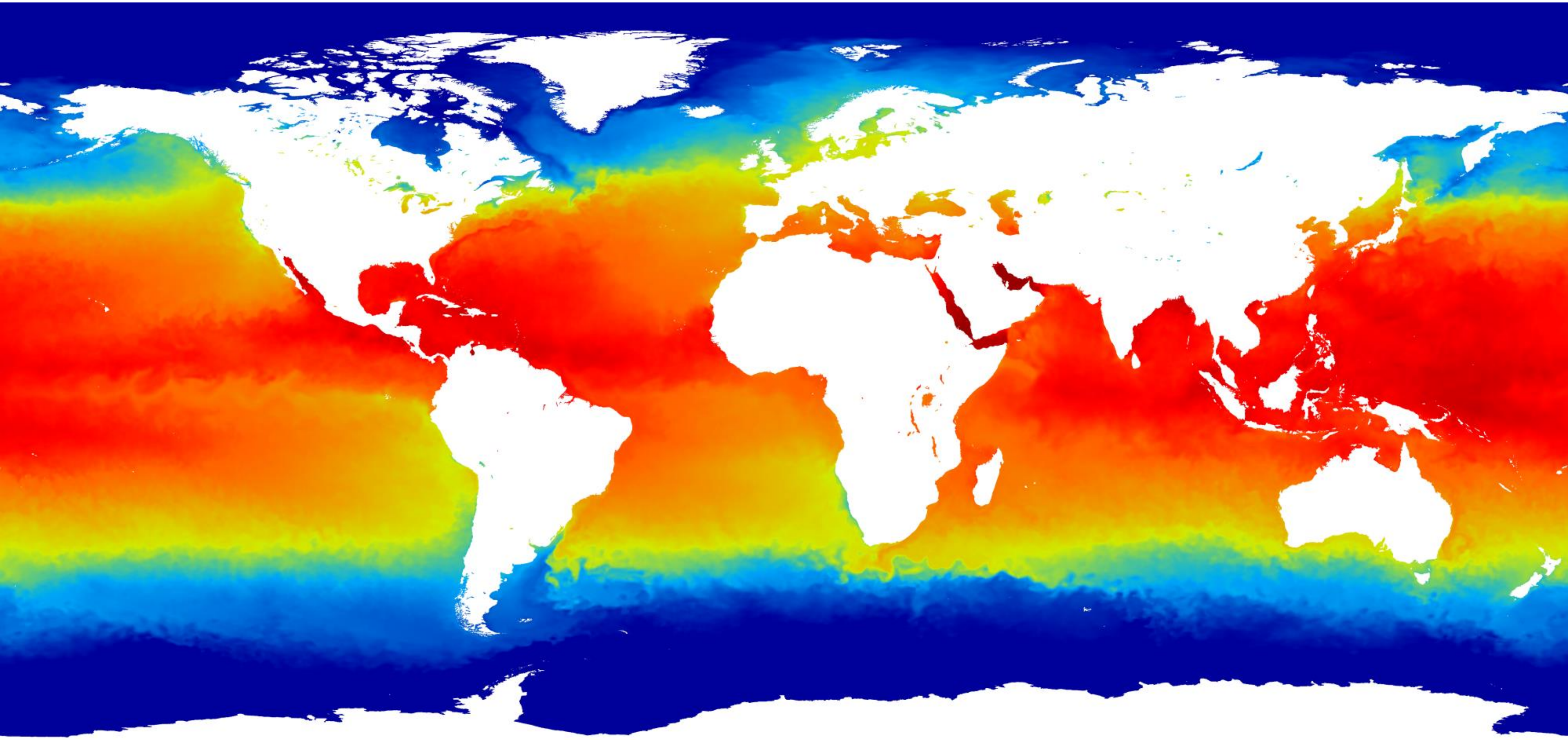
“Level 4” or “SST analysis” :

gap free (interpolated) and probably derived from multiple sensors

i.e., from several L2 and/or L3 data streams



OSTIA analysis from the Met Office (23/9/13)



http://ghrsst-pp.metoffice.com/pages/latest_analysis/ostia.html

Differences between co-located SSTs

- Geophysical
  - radiometric skin depth [0.2 K]
  - time in diurnal cycle [0.1 to 5 K]
- Measurement error
  - noise (random)
  - inverse model (correlated)
  - calibration (systematic)

To obtain optimal combined SST …

- Geophysical
  - radiometric skin depth [0.2 K]
  - time in diurnal cycle [0.1 to 5 K]
- Measurement error
  - noise (random) — Reduce by averaging many observations
  - inverse model (correlated)
  - calibration (systematic)

To obtain optimal combined SST …

- Geophysical
  - radiometric skin depth [0.2 K]
  - time in diurnal cycle [0.1 to 5 K]
- Measurement error
  - noise (random) Reduce statistically, averaging many observations
  - inverse model (correlated)
  - calibration (systematic)

Improve through combining observations appropriately

To obtain optimal combined SST …

- Geophysical
  - radiometric skin depth [0.2 K]
  - time in diurnal cycle [0.1 to 5 K]

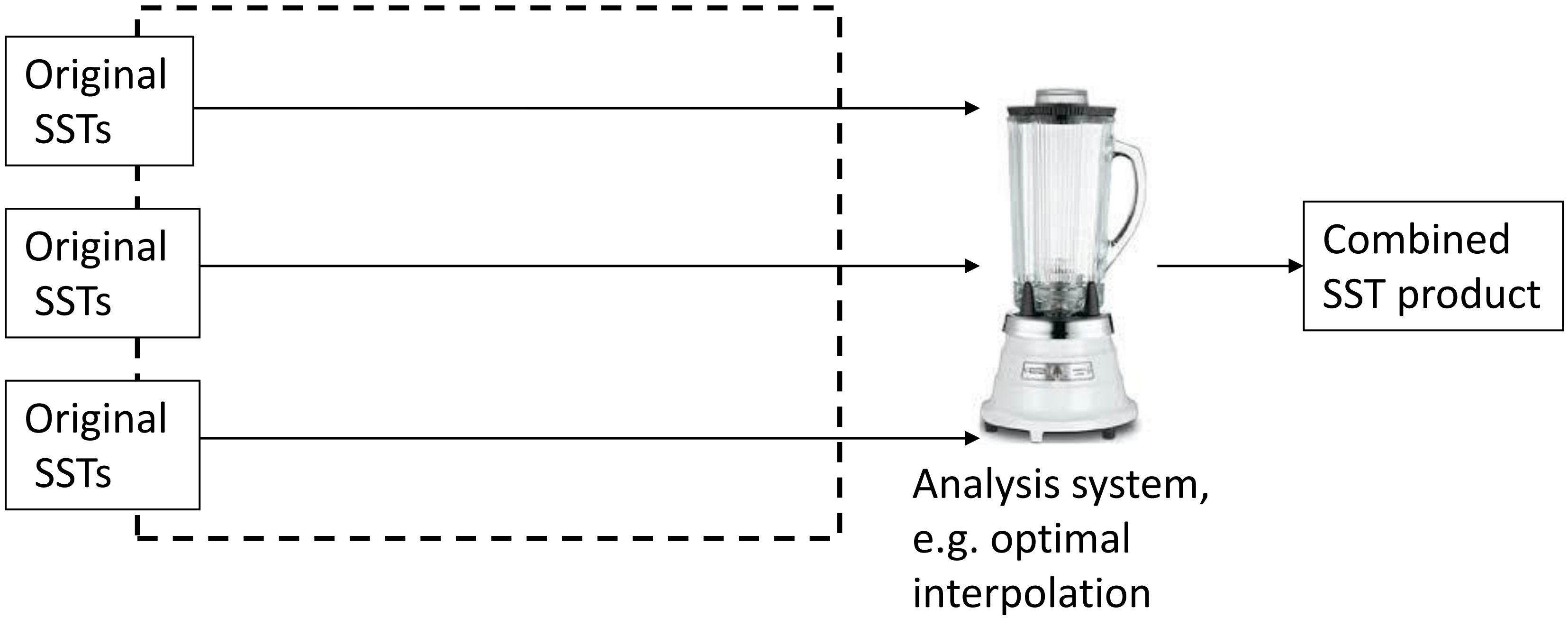
  Respect and preserve these signals

- Measurement error
  - noise (random)

    Reduce statistically, averaging many observations
  - inverse model (correlated)
  - calibration (systematic)

    Improve through combining observations appropriately

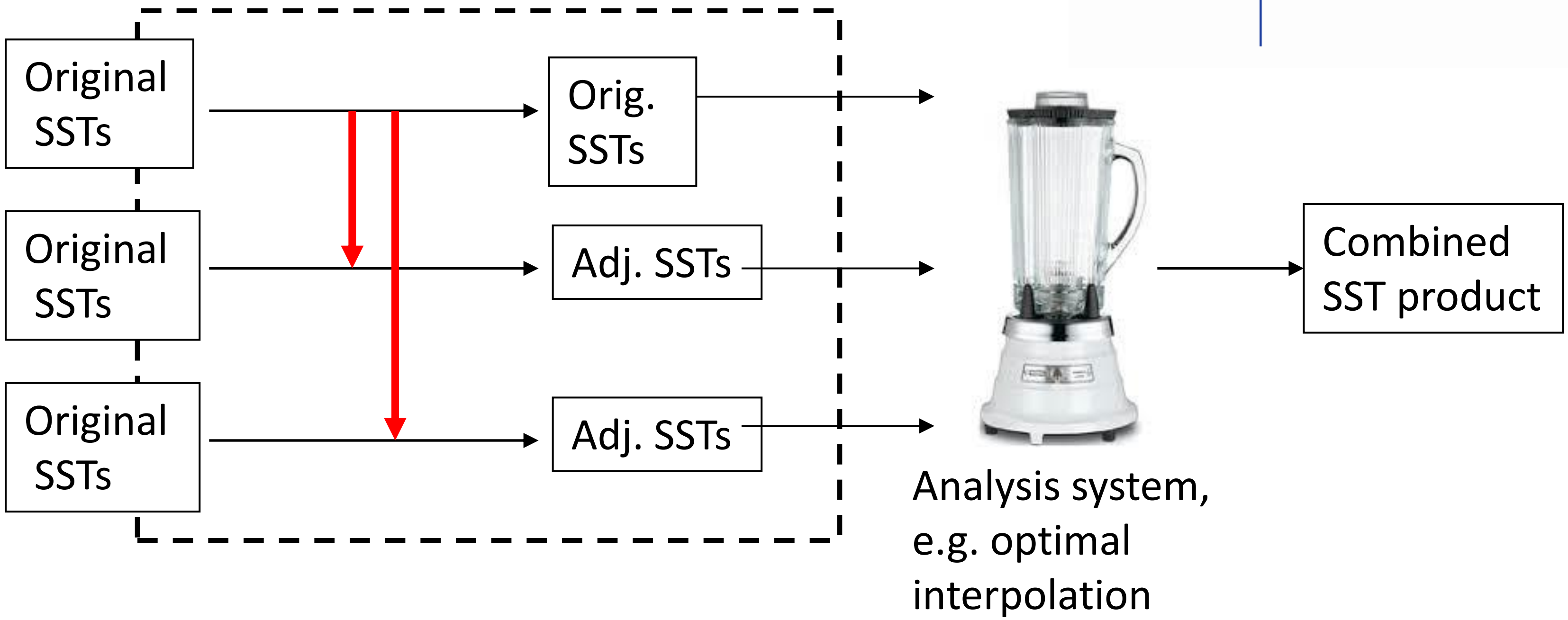
Exploiting system of sensors:
Earliest approaches were the most direct



Exploiting system of sensors:
Use of dual-view reference sensor for SST adjustment

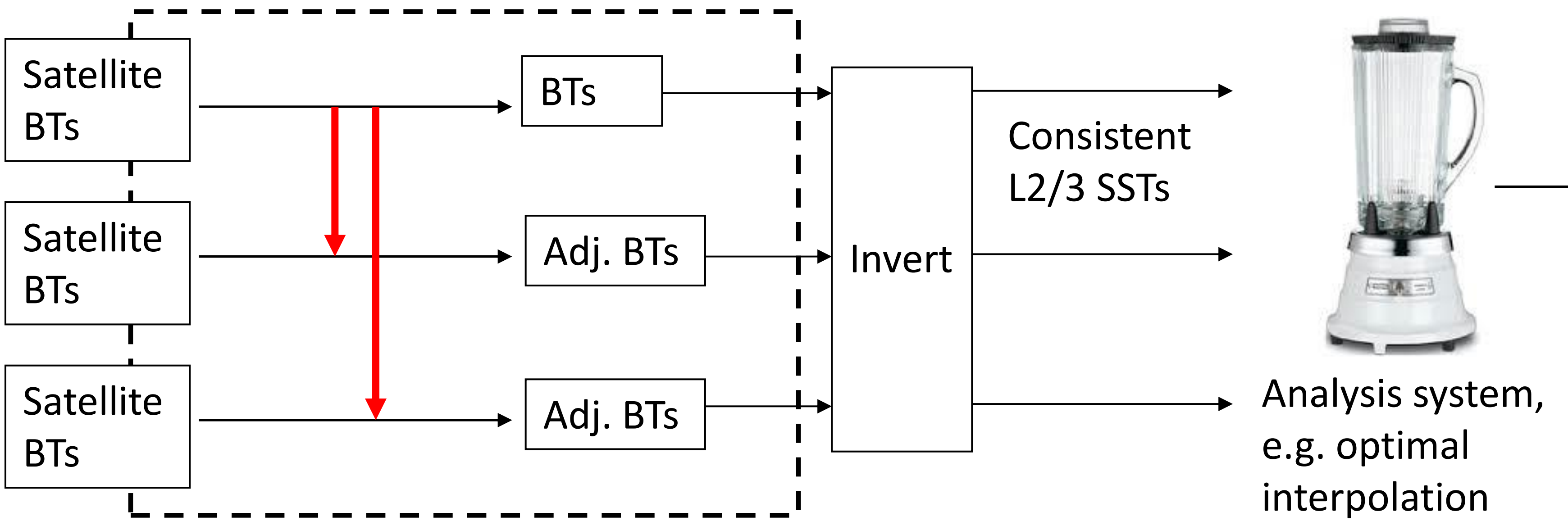
Operational example:
OSI-SAF (www.osi-saf.org) bias adjustment to AATSR

The EUMETSAT Network of Satellite Application Facilities
OSI SAF
Ocean and Sea Ice



Exploiting system of sensors:
Use of reference sensors for BT adjustment

Approach used in SST CCI – i.e., only in climate context, not yet operationally



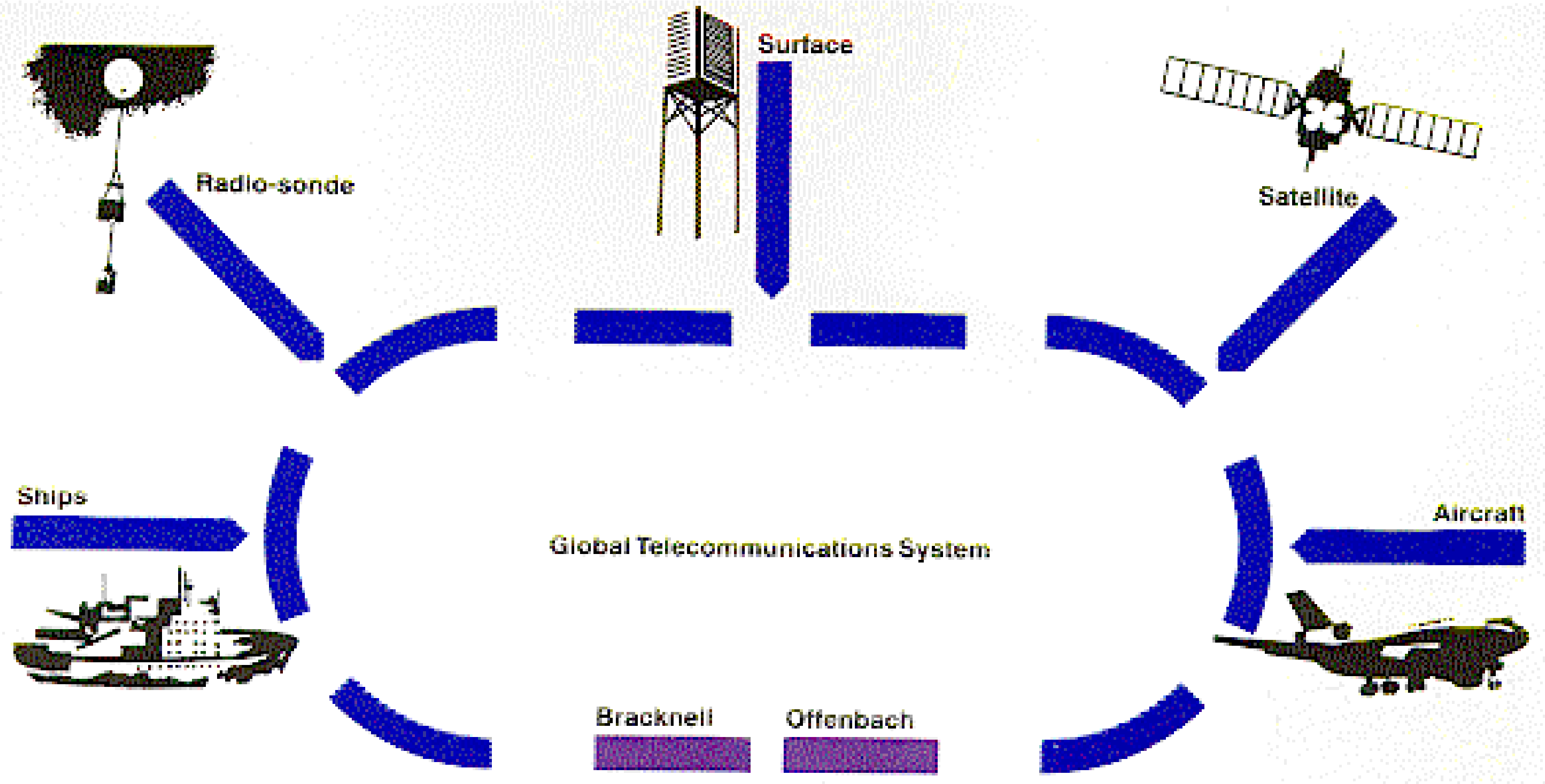
Need **multi-sensor matches** with data for the main factors related to real geophysical differences and biases for each sensor & channel

SYSTEM – OPERATIONAL USES NWP & OCEANOGRAPHY

The weather forecast process

- NUMERICAL WEATHER PREDICTION
- 1. Gather observations for the globe to define the “current state” of the atmosphere
  - Collect observations
  - Perform quality control
- 2. Use these observations in a model that describes how the the atmosphere changes with time
  - Data assimilation
- 3. Take this as the “current” state of the atmosphere and run the same model into the future
  - Stop after 24, 48, 72 hours and interpret weather forecast!

Observational data gathering



ON HANDOUT

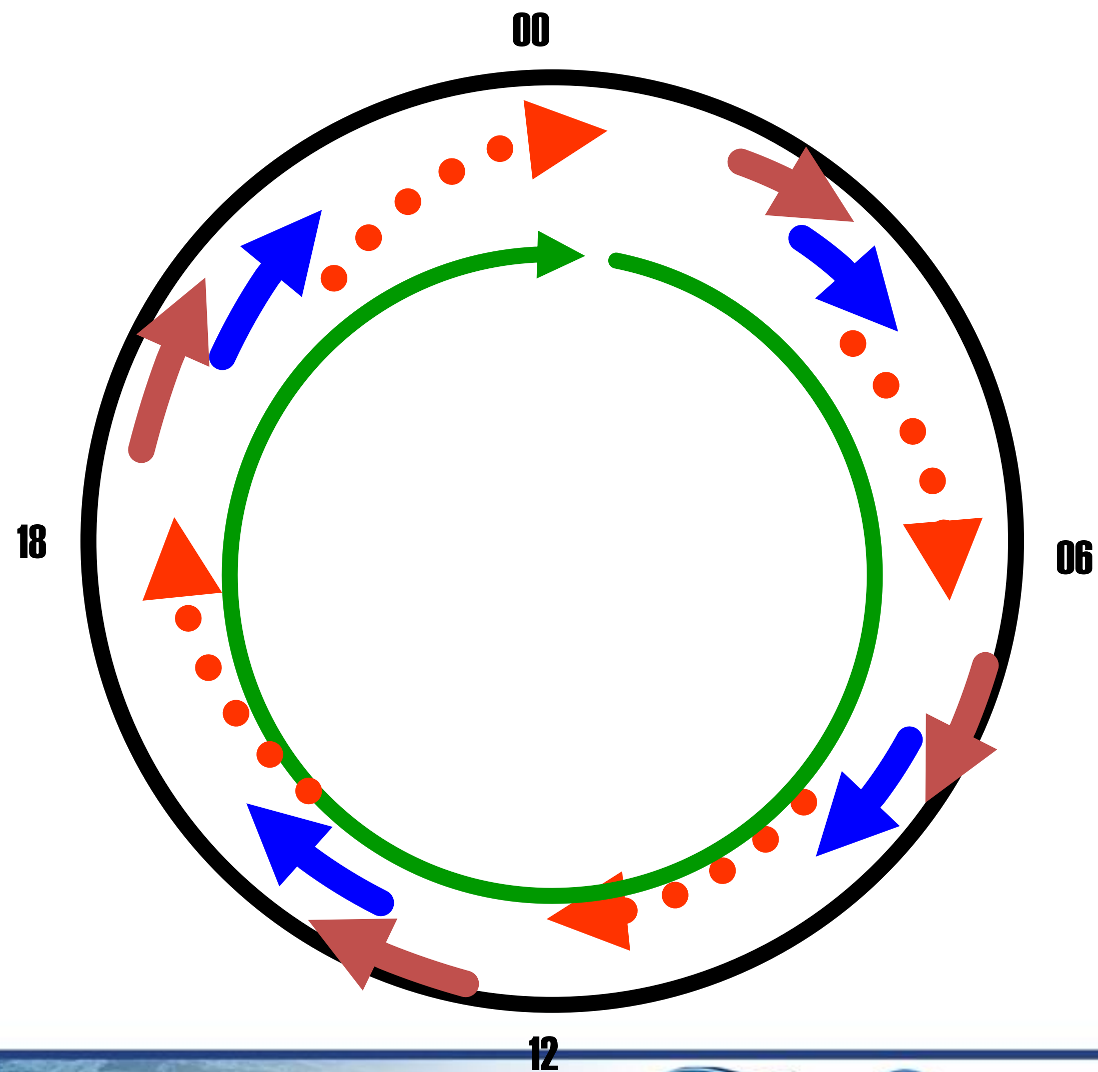
The forecast cycle over 24 hours

Data gathering

Quality control

Assimilation

Forecast



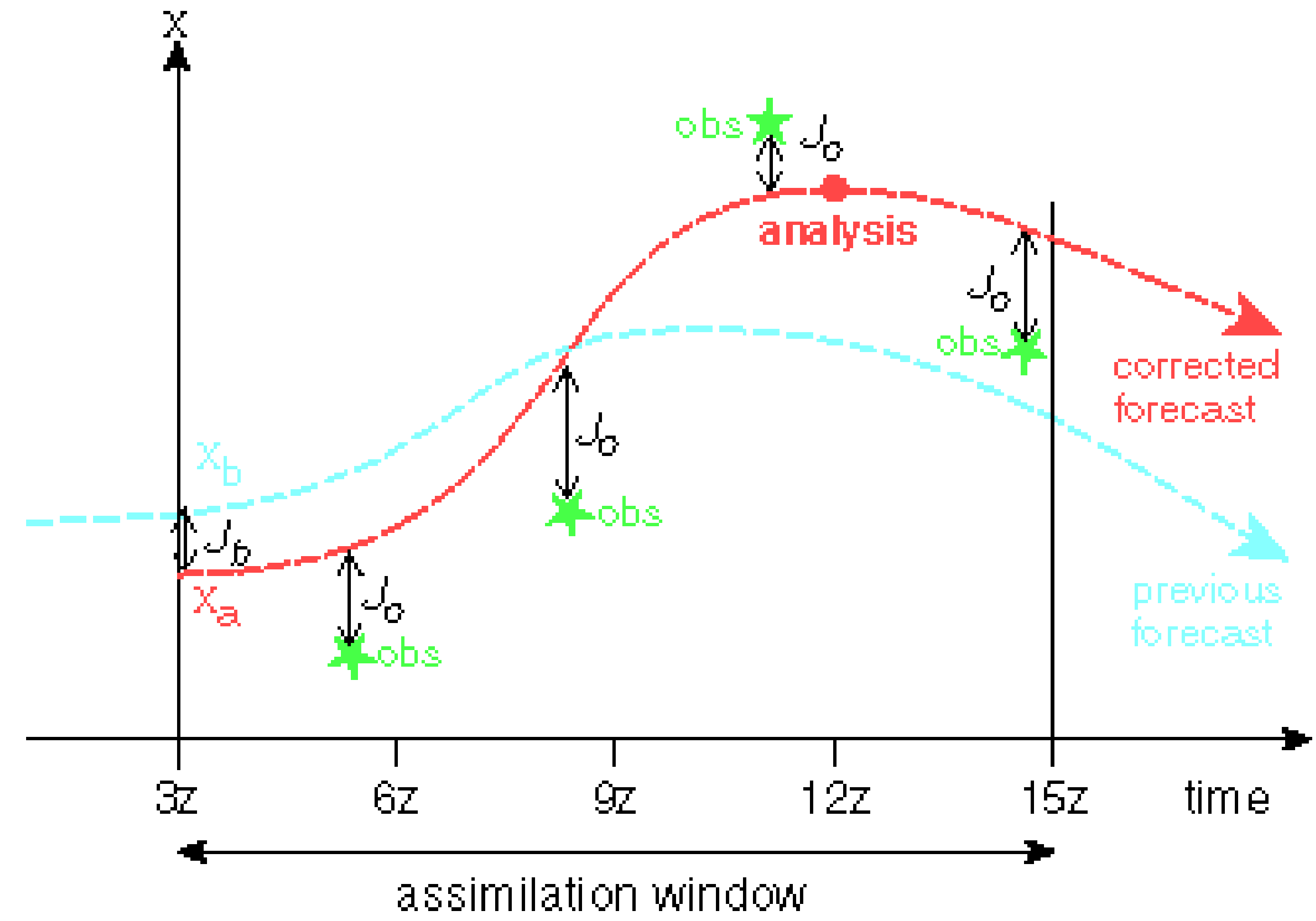
Data assimilation

- Observations and their uncertainties are "assimilated" into NWP model:
  1. Interpolate observations onto model horizontal and vertical grid
  2. Combine latest observations with previous=background forecast
  3. Perform adjustments

Combine new observations with previous forecast

- Adjust the model background field -the forecast from the previous model run- towards the new data received from observations
- Include observational uncertainty to determine how reliable these new data are
- Process is very complex and known as variational analysis
- Data assimilation can take 30% of the computational effort

Data assimilation- schematic



Current use of SST

- SSTs are generally NOT assimilated
- SSTs are generally "prescribed" during the forecast period

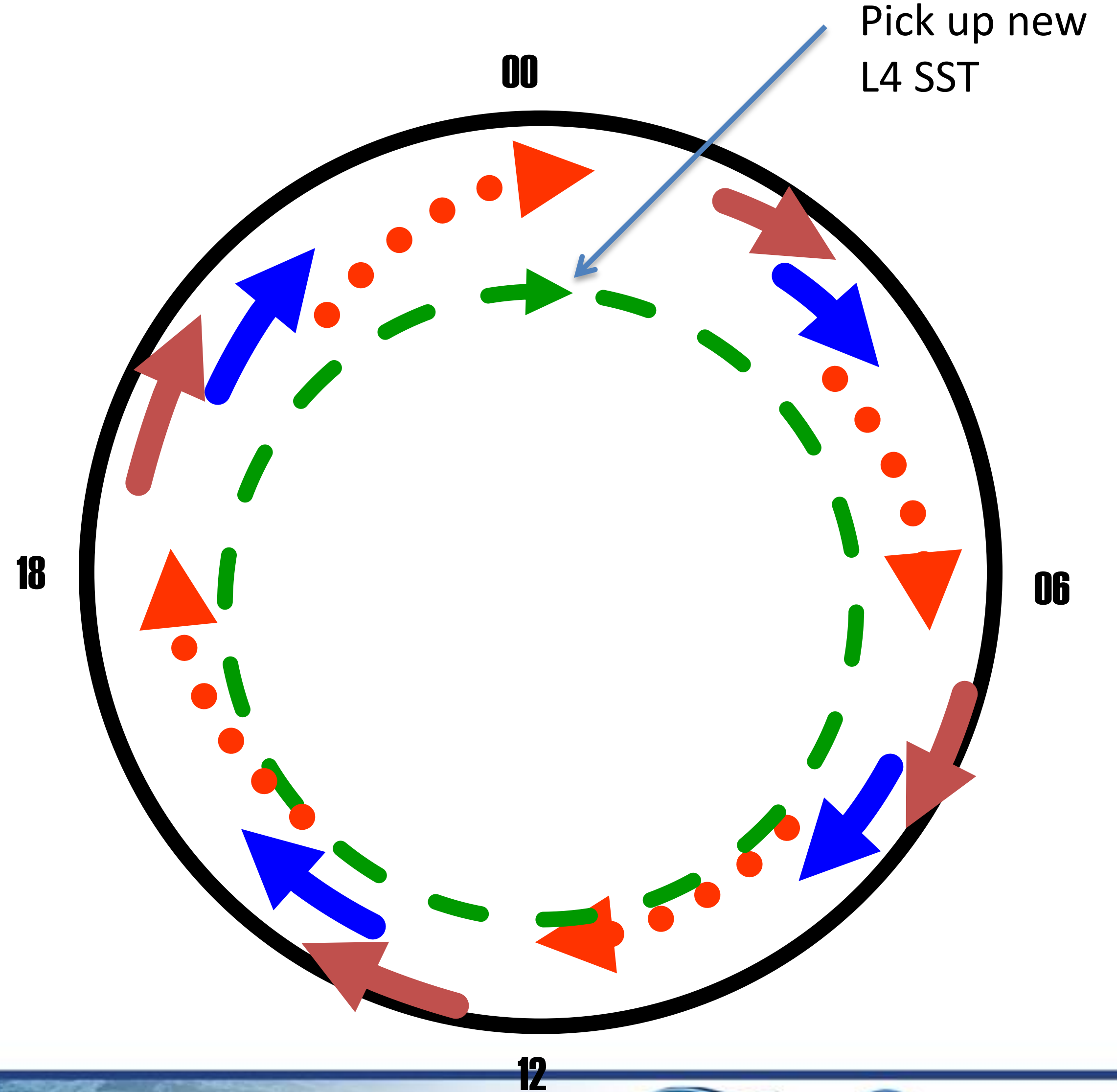
The forecast cycle over 24 hours for SST

Use prescribed SST

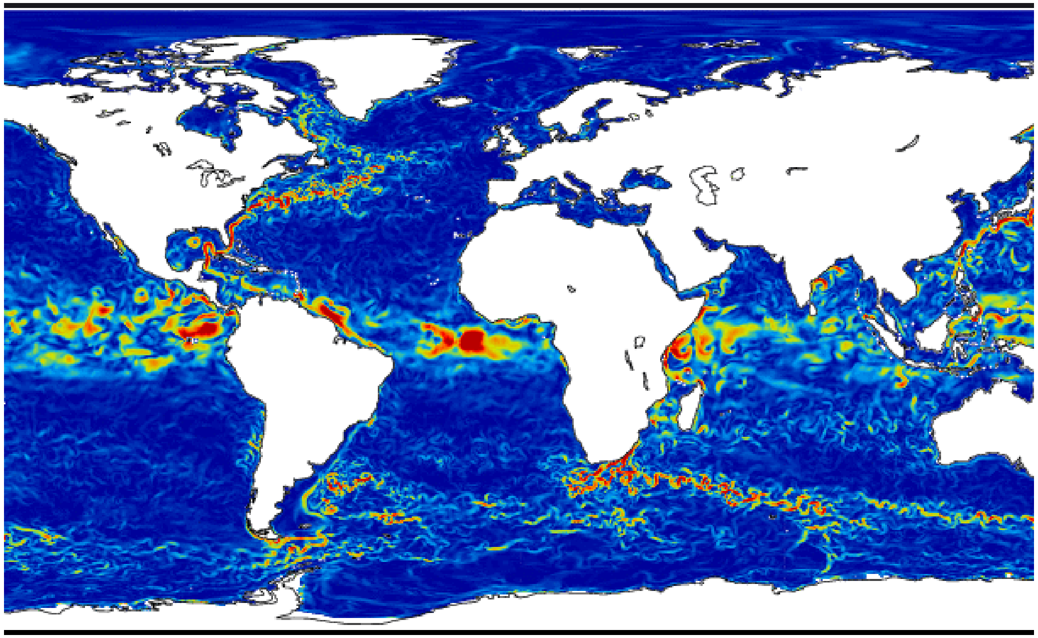
Quality control

Assimilation

Forecast



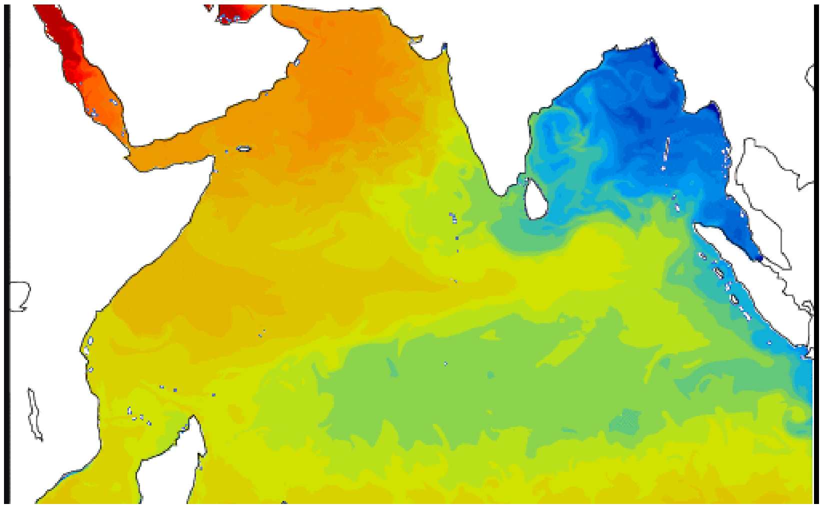
Global Ocean Analysis / Forecasting



Analysis for 23/9/2013
Surface currents

UK Met Office creates a 3-D ocean forecast out to 7 days
Fields of 3-dimensional ocean currents, temperature, salinity and sea ice concentration, thickness and velocity

FOAM assimilation example



Indian Ocean salinity fields
FOAM 23/9/2013

Observations from the previous 2 days are assimilated including:

- temperature and salinity profiles including data from Argo profiling floats, the TAO/TRITON, PIRATA and RAMA moored arrays as well as XBTs and CTDs
- sea-surface height data from satellite altimeters Jason-1, Jason-2 and Envisat
- ship, buoy and satellite sea-surface temperature observations
- the EUMETSAT OSI-SAF sea-ice concentration fields