climate change initiative

→ SEA SURFACE TEMPERATURE

A 42-year Sea Surface Temperature Climate Data Record from the ESA Climate Change Initiative

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sst cci

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SST-CCI Climate Data Record v3

- ESA Climate Change Initiative (CCI) has produced two previous SST Climate Data Records (CDR):
  - Version 1: September 1991 – December 2010 (19 years)
  - Version 2: September 1981 – December 2016 (35 years)
- Version 3:
  - CDR: January 1980 – December 2021 (42 years)
  - Interim-CDR (ICDR) 2022 to present at ~3 weeks latency

Improved AVHRR SST especially 1980s:

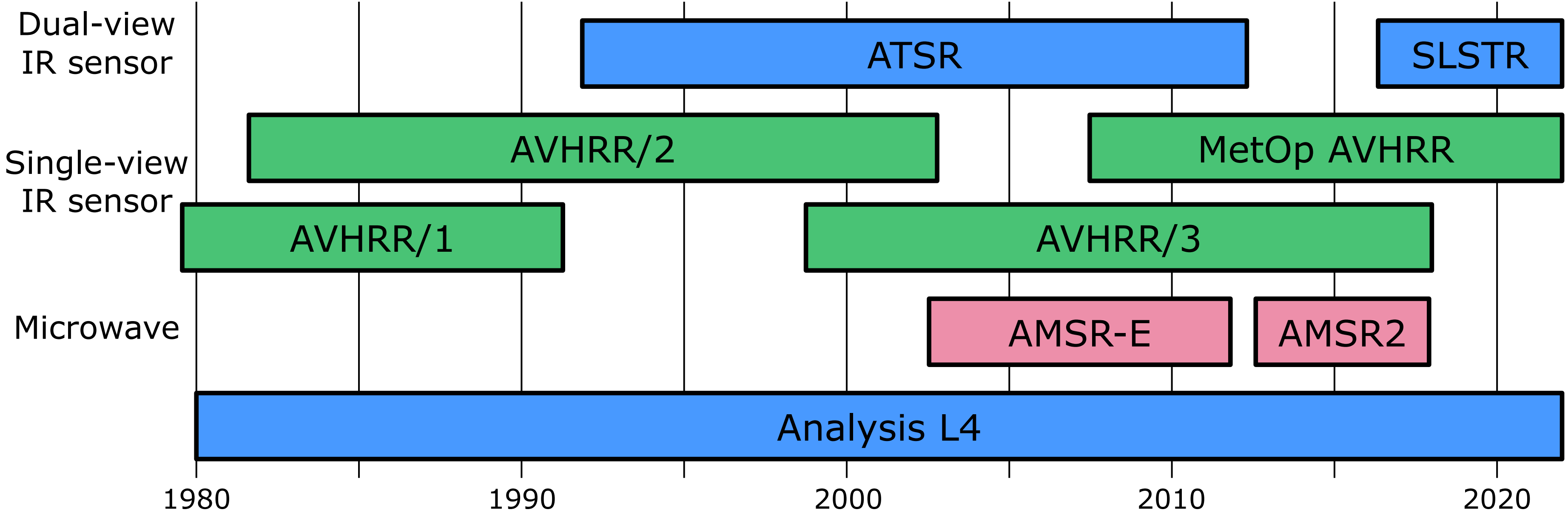
- Addition of AVHRR/1 from NOAA-6, -8, and -10
- Reduce 1980s data gaps
- Reduce desert-dust related biases
- New bias-aware optimal estimation retrieval

New:

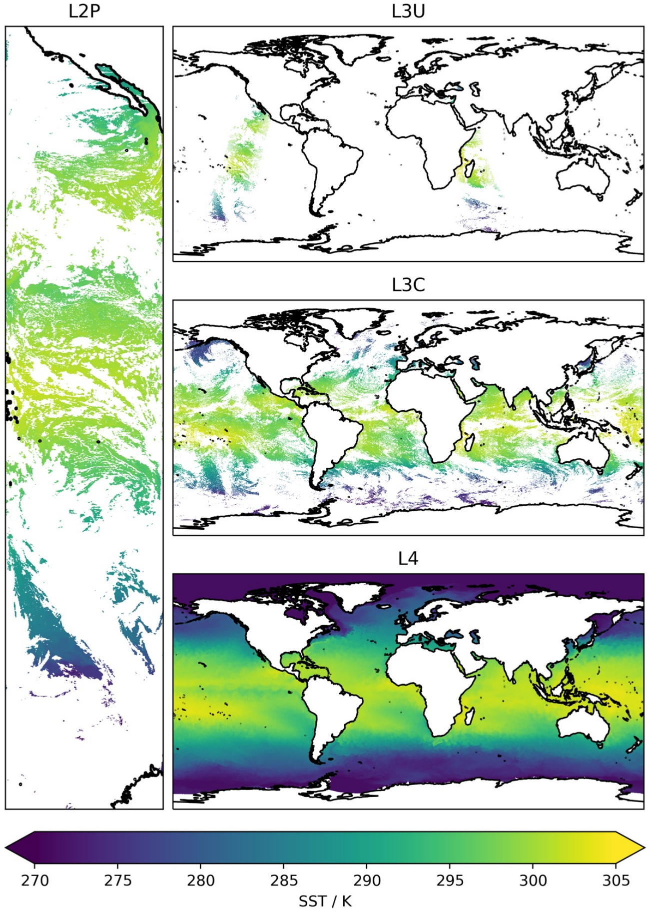
- Full resolution MetOp AVHRR
- SLSTR
- Passive Microwave SST from AMSR-E and AMSR2

SST-CCI Climate Data Record v3

- Includes products at L2P, L3U, L3C, and L4
- SST_{skin} at satellite overpass; SST_{20cm} at 10:30 local time
- Multi-sensor L4 Analysis generated using Met Office OSTIA system



Product Levels



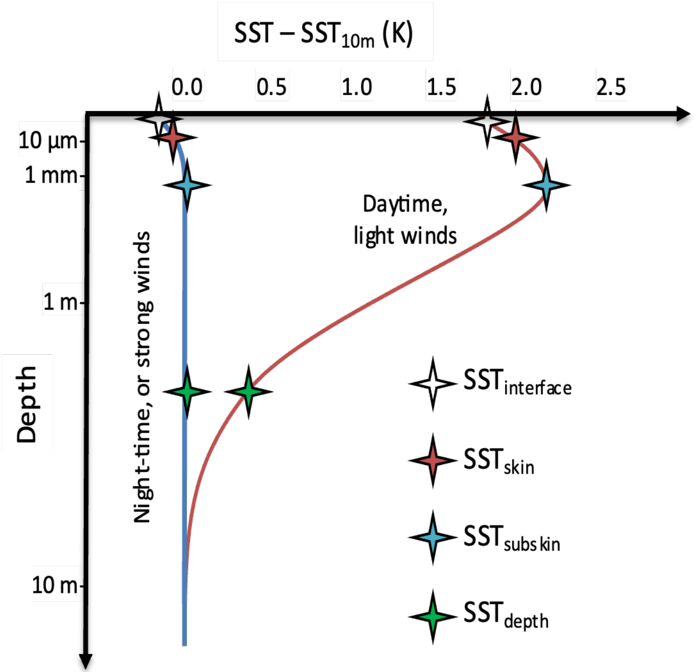
SST is provided at four “product levels”:

- **L2P**: data on the Level 1 grid – i.e. satellite swath projection
- **L3U**: (uncollated) Level 2 data remapped to global latitude / longitude grid
- **L3C**: (collated) single-sensor observations for a fixed period (daily)
- **L4**: multi-sensor observations blended to a global gap-free product

SST Type

SST can refer to anything between the interface and ~10 m, which varies due to heat flux through the surface.

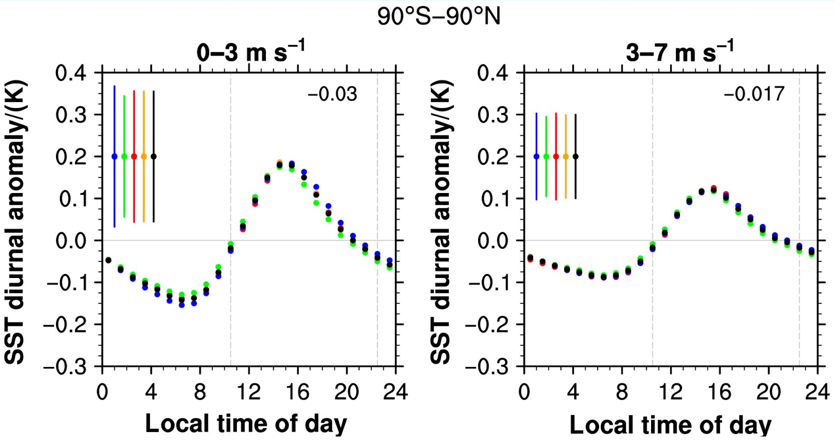
- **SST_{int}** – is a hypothetical temperature at the exact air-sea interface.
- **SST_{skin}** – the skin temperature measured by an infrared radiometer, corresponds to a depth of ~10-20 µm. This is typically ~0.2 K cooler than in situ measurements (depending on wind speed).
- **$SST_{subskin}$** – the sub-skin temperature. For practical purposes the sub skin can be approximated as the temperature observed by a microwave radiometer.
- **SST_{depth}** – temperature measured at any depth below the surface (e.g. $SST_{0.2m}$), used for the majority of *in situ* measurements (e.g. drifting buoys, ships etc.)

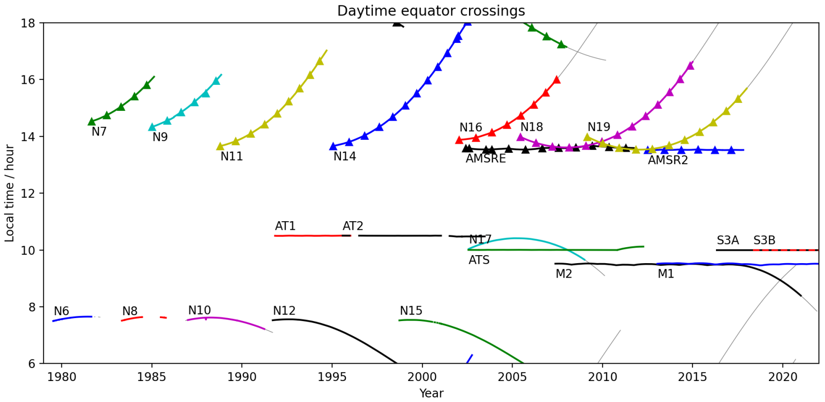


Diurnal Variability

- SST varies through the day as it is warmed by the sun, and cools at night
    - Typical diurnal cycle is 0.1 – 0.5 K
    - Can be over 5 K in extreme cases (low wind, strong sun)
- Satellites observe at various local times of day
- Some satellites are in drifting orbits

- Climate Data Record needs to use standard time of day to avoid aliasing diurnal cycle
- SST CCI uses 10:30 or 22:30 local time
- Diurnal anomaly is closest to zero, SST is good approximation for daily average SST



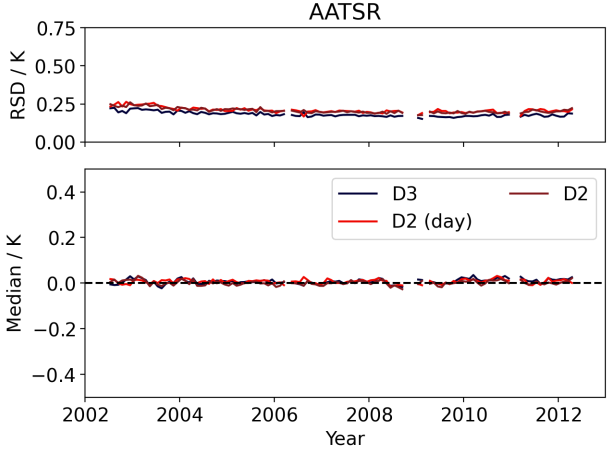


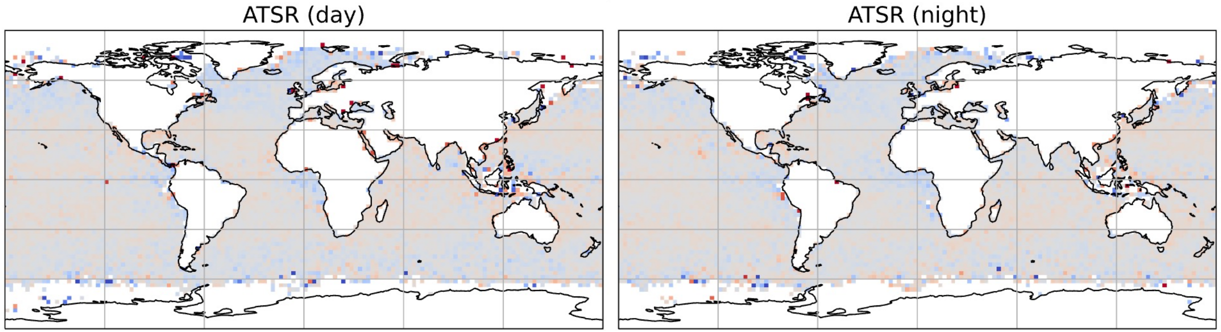
Morak-Bozzo et al. 20160, Geosci. Data J., doi:10.1002/gdj3.35

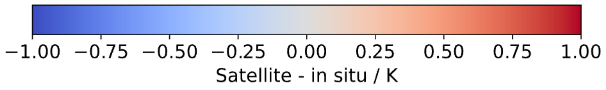
Dual View Reference Sensors

ATSR

- Unchanged since version 2.1
- Bayesian Cloud detection
- Dual-view coefficient retrieval
    - Based on radiative transfer modelling (LBLRTM)
    - Aerosol robust
    - Fully independent from *in situ*





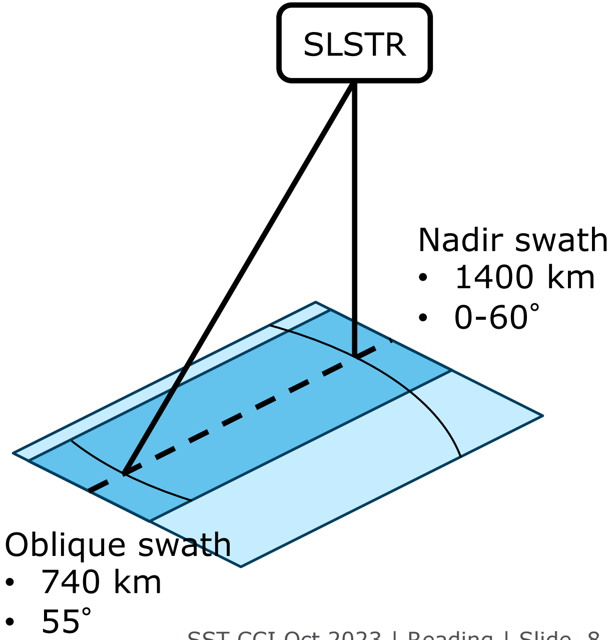


Merchant et al. 2019, Sci Data, doi:[10.1038/s41597-019-0236-x](https://doi.org/10.1038/s41597-019-0236-x)

Dual View Reference Sensors

SLSTR

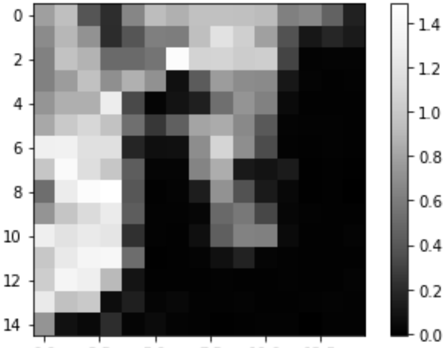
- Same fundamental methods as ATSR (Bayesian cloud + dual-view coefficients)
- More complex viewing geometry, wider asymmetric nadir swath
    - CDR processing limited to dual-view overlap
- Two resolutions
    - 500m solar bands (S1 – S6)
    - 1 km thermal infrared (S7 – S9)
- Level 1b products are presented on a regular grid aligned with sub-satellite track
- Centre of “observation” can be up to ½ pixel from nominal location on grid



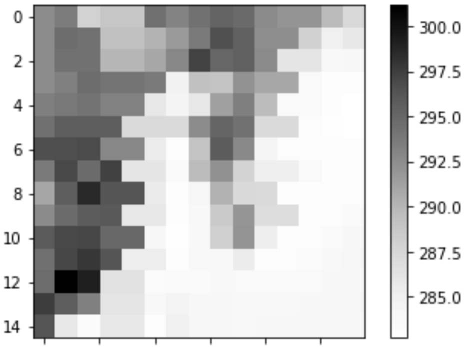
SLSTR Regridding

- Centre of “observation” can be up to ½ pixel from nominal location on grid
- Cannot use simple 2x2 averaging to map Vis/NIR to TIR channels
  - Misalignment of Vis/NIR will cause cloud detection errors

Coastal example were alignment of TIR scan and nominal grid results in saw tooth edge as “best” IR pixel alternates +½ and −½ offset



Vis: 2x2

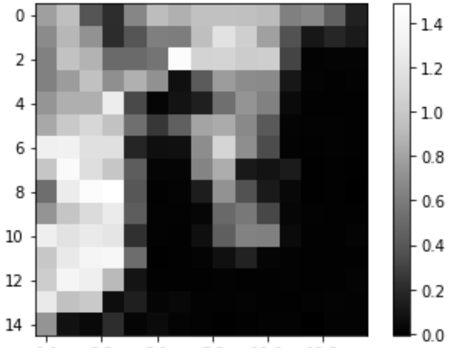


TIR

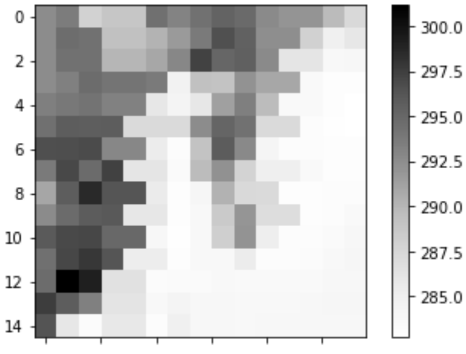
Bulgin et al. 2023, RSE, doi:10.1016/j.rse.2023.113531

SLSTR Regridding

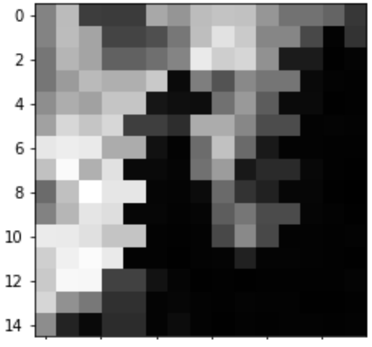
- Need to collocate Vis/NIR channels with actual location of 1 km TIR pixels
  - L1b includes both cartesian and geodetic coordinates for every pixel
  - Use k-nearest neighbors to regrid Vis/NIR to TIR pixel locations
    - Include orphan pixels
    - Exclude cosmetic fill



Vis: 2x2



TIR

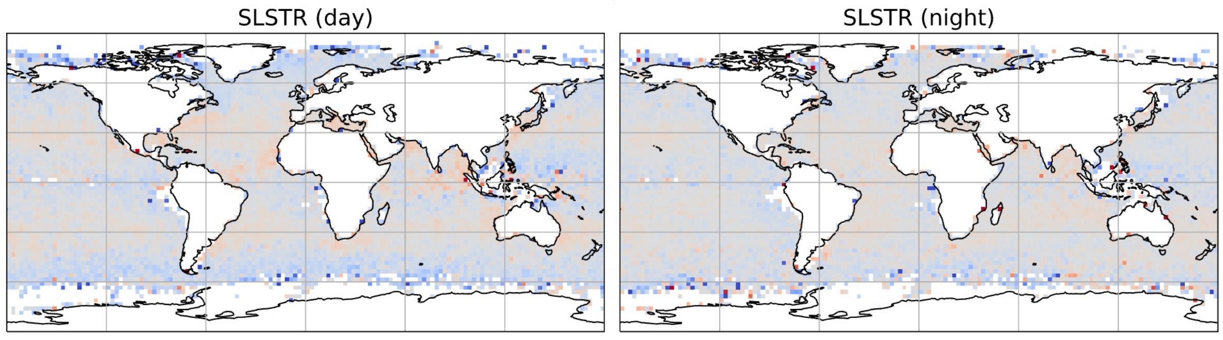


Vis: k-nearest

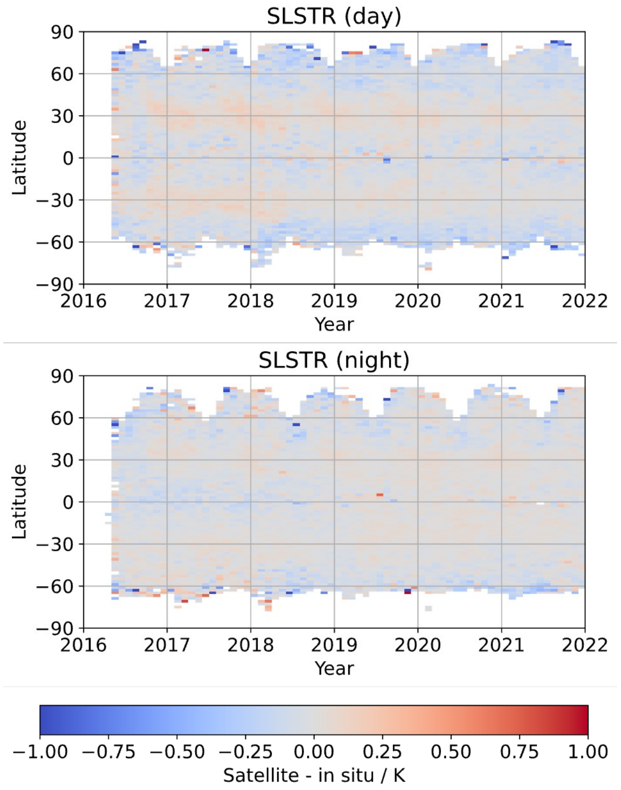
Bulgin et al. 2023, RSE, doi:[10.1016/j.rse.2023.113531](https://doi.org/10.1016/j.rse.2023.113531)

SLSTR Performance

Comparable to ATSR2 / AATSR



	Day Bias	Day RSD	Night Bias	Night RSD
ATSR-2	-0.00	0.28	+0.02	0.24
AATSR	+0.01	0.21	+0.01	0.18
SLSTR-A	+0.02	0.25	+0.00	0.19
SLSTR-B	-0.03	0.24	-0.01	0.19



Single-view AVHRR sensor

AVHRR

- Bayesian Cloud Detection
- Bias-aware Optimal Estimation (OE)
    - Basic OE assumes *a priori* and forward model are zero mean bias and error covariances are known
    - BAOE estimates biases and covariances using a reference dataset

Forward model

- RTTOV 12.3

Improved prior

- CDRv2.1 for SST
- CAMS aerosol – including dust

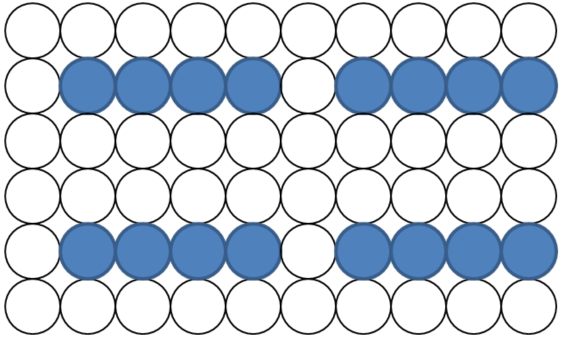
Bias-aware OE

- NOAA AVHRR – *in situ*
- MetOp AVHRR – AATSR + SLSTR

Merchant et al. 2020, RSE, doi:10.1016/j.rse.2019.111590

MetOp AVHRR

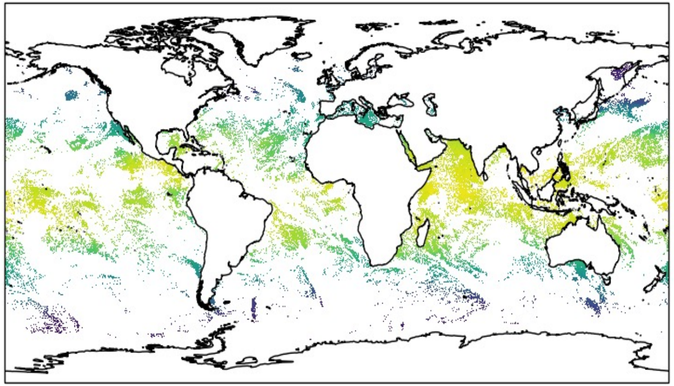
- Most AVHRR data are “GAC” resolution
  - “Global Area Coverage”
  - Approximately 4 km size at nadir



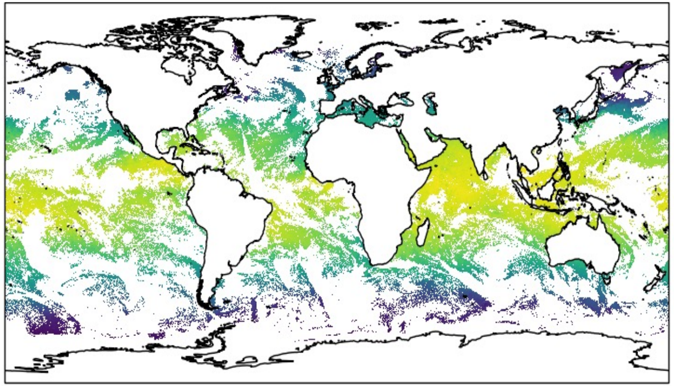
GAC pixels (blue) are average of 4 full resolution pixels. White pixels are unused in GAC data

- CDRv2 used MetOp AVHRR at GAC resolution
- CDRv3 uses MetOp AVHRR at full resolution
  - 15 times as many pixels at Level 1 and 2
  - Improves coverage at Level 3

GAC Resolution

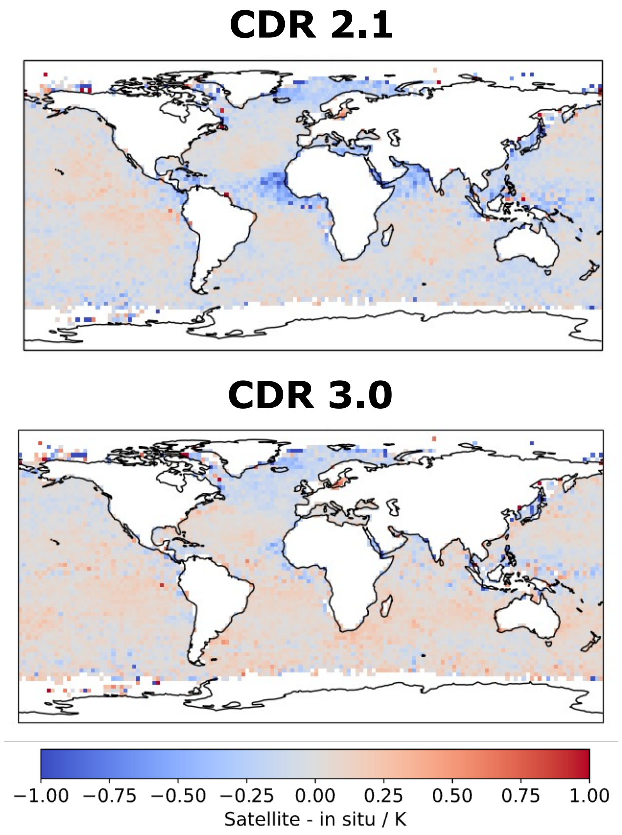


Full Resolution



AVHRR: Reduced desert-dust biases

- CDR v2 AVHRR data was affected by cold-biases due to desert-dust aerosol
  - Strong seasonal cycle with biases in Atlantic Ocean and Arabian Sea
  - Previous retrieval assumed “clear-sky” with no aerosol present
- CDR v3 adds CAMS aerosol data to prior
  - Includes dust component
  - 2003 – 2021: CAMS reanalysis
  - Otherwise: CAMS Climatology (Bozzo et al.)
  - Greatly reduces dust biases in AVHRR SST data



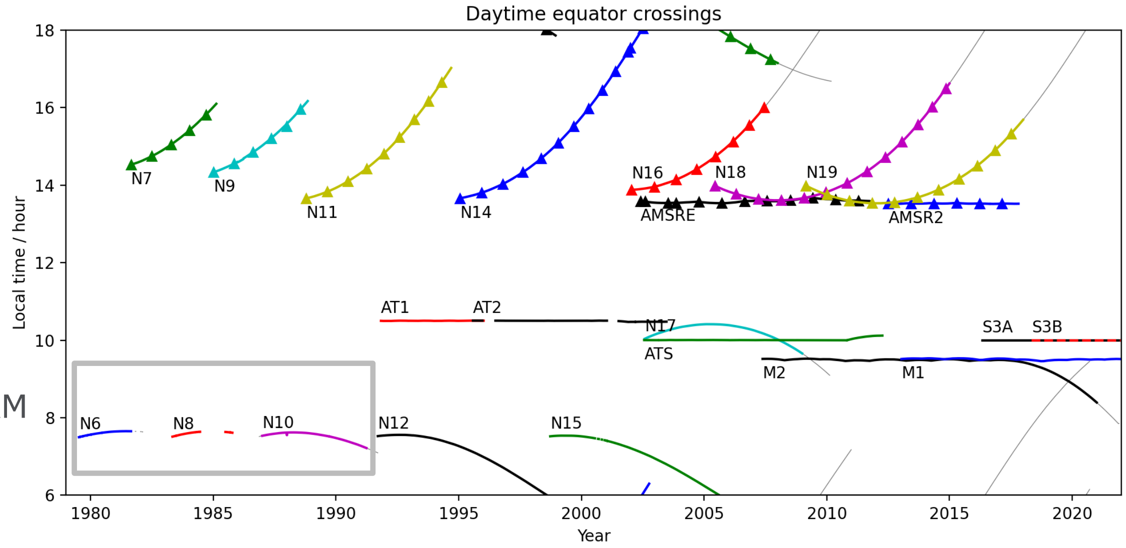
Right: NOAA-19 AVHRR daytime minus drifter SST

Bozzo et al. 2020, Geosci. Model Dev., doi:[10.5194/gmd-13-1007-2020](10.5194/gmd-13-1007-2020)

AVHRR/1 instruments

- AVHRR/1 instruments had four channels: 0.6, 0.8, 3.8, 11 µm
  - Solar signal affects SWIR, so two channel retrieval only possible at night
- AVHRR/1 used on NOAA-6, -8, and -10 platforms
  - Only sensor available before August 1981

- Not processing TIROS-N in CDRv3



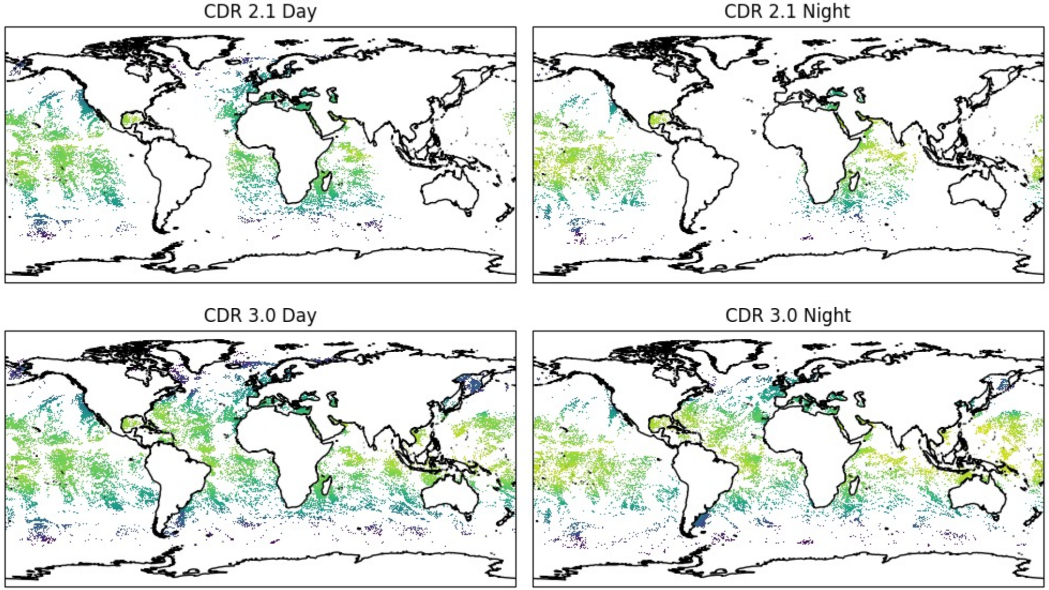
Right: Satellite equator crossing times

AVHRR/1 instruments were used for the AM orbit until September 1991

Grey = data not used in CDRv3

Recovered AVHRR orbits

- CDRv2 was affected by AVHRR processing failures in 1980s
  - Due to QC checks falsely flagging data received via Wallops Island
  - Resulted in some intermittent coverage gaps during 1980s

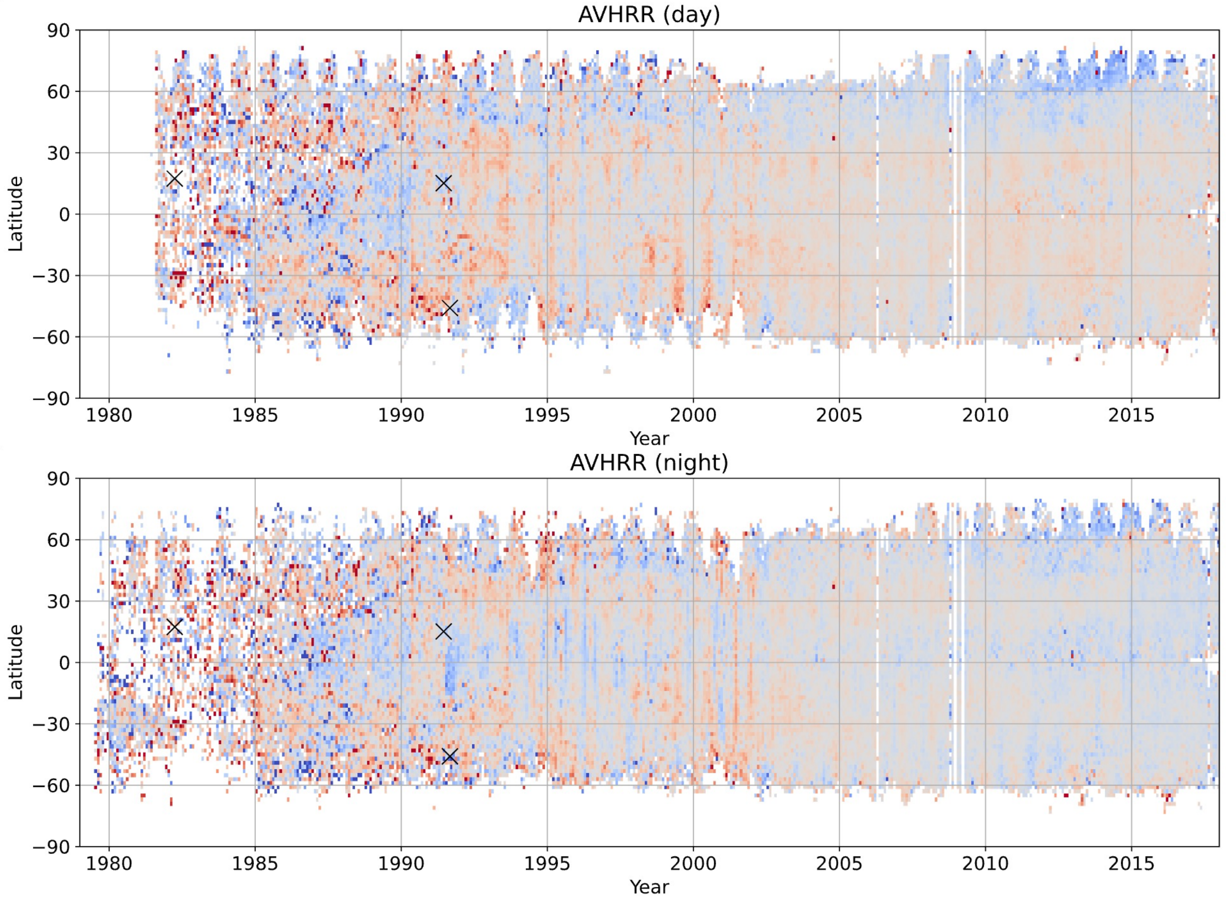


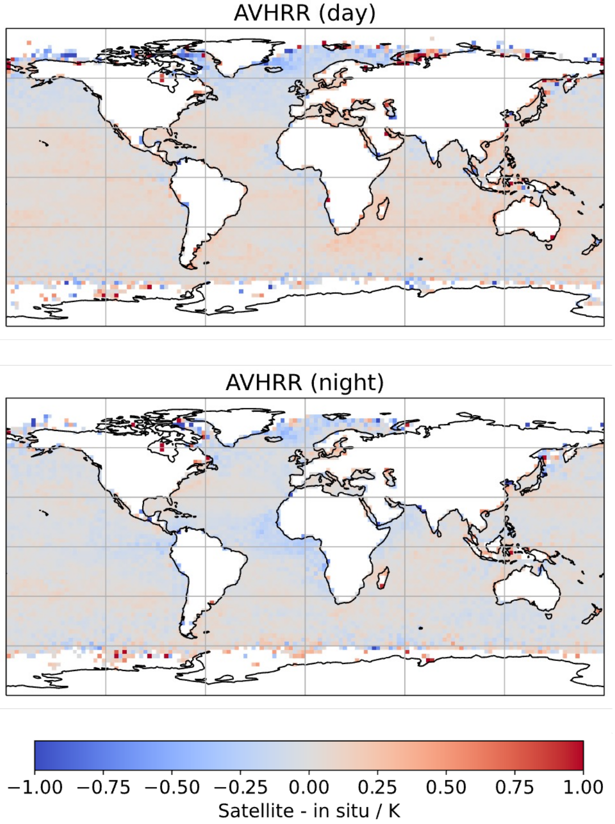
AVHRR11_G from 1989-06-20

Top: CDR v2 orbits from WI are missing

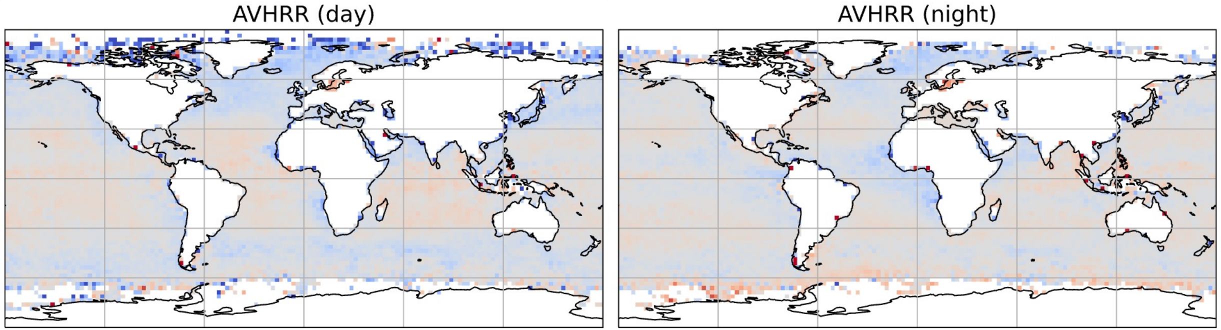
Bottom: CDR v3 all orbits processed

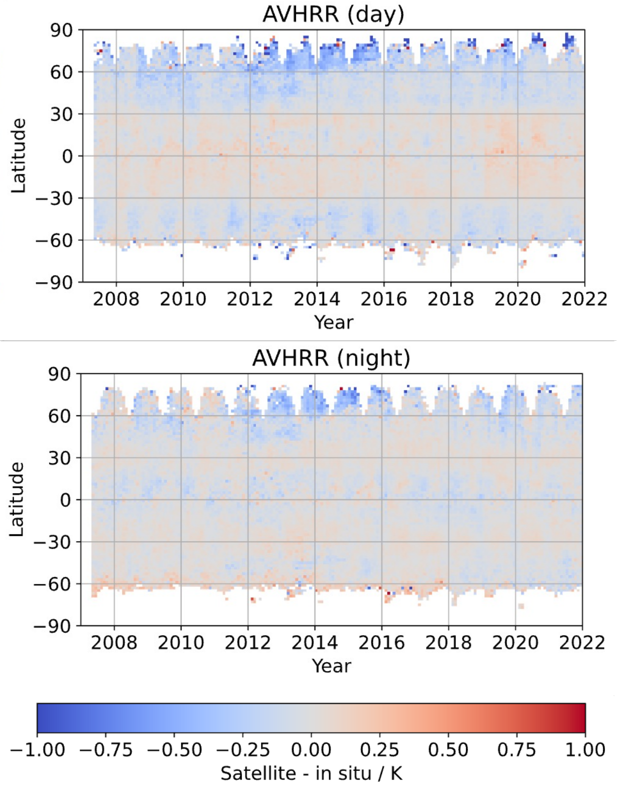
NOAA AVHRR Performance





Metop AVHRR Performance





- Cold bias seen in Arctic SST 2012 – 2015
- Corresponds to dual-view data gap
- But also seen in unrelated non-CCI products
  - e.g. ACSPO MODIS and VIIRS
- Required further investigation, may indicate a problem with *in situ* measurements

Quality Level (IR Sensors)

- Each pixel is assigned a quality level
- Based on cloud mask (probability of clear), retrieval sensitivity, or goodness-of-fit test (chi-square)
- QL 4 and 5 recommended or climate applications
- QL 2 and 3 usable for qualitative applications

Level	Meaning	P(clr)	Sens.	Chi^2	Other
0	No data	<0			No data; land pixel
1	Bad data	<0.5	<0.0	>3	SST < 271.15; ice detected, NWP missing
2	Worst quality	<0.8	<0.1	>2	Limb pixel (θ_{sat} > 60)
3	Low quality	<0.9	<0.2	>1	Twilight (87.5 < θ_{sol} <92.5
4	Acceptable				ATSR: aerosol detected AVHRR: solar contamination detected
5	Best quality				

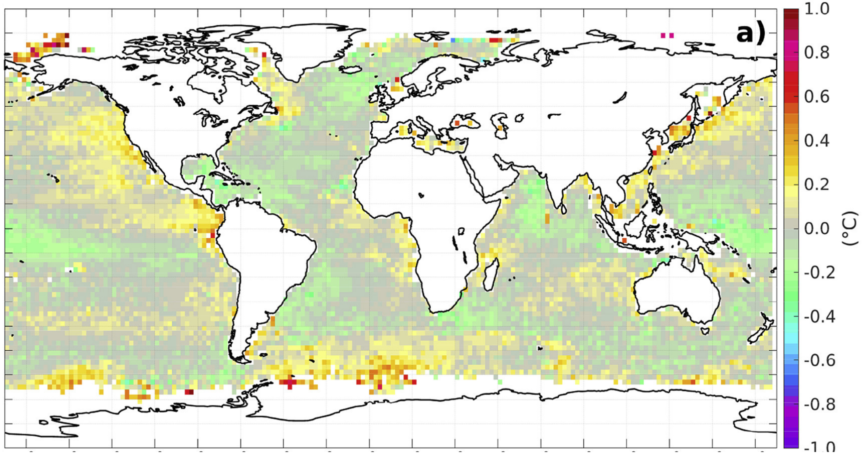
GHRSST Science Team, 2012, Zenodo, doi:10.5281/zenodo.4700466

Microwave: AMSR

AMSR

- Microwave products were experimental in Phase 2, now included in CDR v3
  - Not affected by cloud, aerosol, water vapour distribution etc.
  - Larger footprint (40 – 70 km)
  - Limited by proximity to land, sea-ice, RFI, and precipitating cloud
- Retrieval is a two-step linear regression to *in situ*

Sensor	QL	Mean / K	Std. / K
AMSR-E	3	+0.02	0.64
	4	-0.01	0.51
	5	-0.03	0.37
AMSR2	3	+0.02	0.64
	4	+0.01	0.52
	5	-0.00	0.35



Alerskans et al. 2020, RSE, doi:10.1016/j.rse.2019.111485

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AMSR

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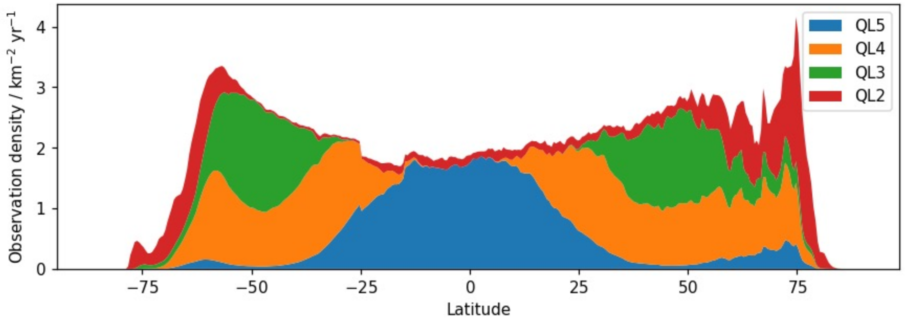
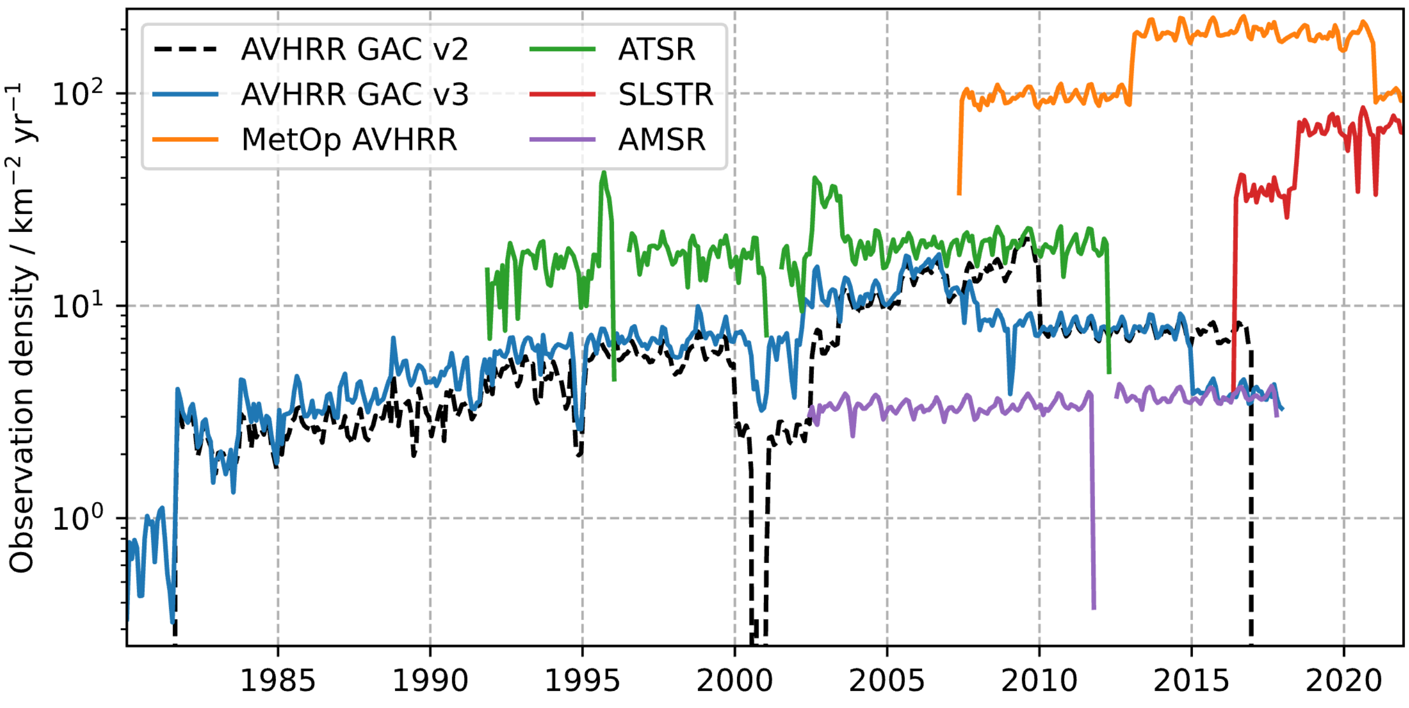
  - Not affected by cloud, aerosol, water vapour distribution etc.
  - Larger footprint (40 – 70 km)
  - Limited by proximity to land, sea-ice, RFI, and precipitating cloud
- Retrieval is a two-step linear regression to *in situ*
- QL is based on retrieval uncertainty – so QL 5 limited to tropics

Sensor	QL	Mean / K	Std. / K
AMSR-E	3	+0.02	0.64
	4	-0.01	0.51
	5	-0.03	0.37
AMSR2	3	+0.02	0.64
	4	+0.01	0.52
	5	-0.00	0.35



Alerskans et al. 2020, RSE, doi:[10.1016/j.rse.2019.111485](https://doi.org/10.1016/j.rse.2019.111485)

Single-Sensor Data Density



New in CDRv3

- MetOp AVHRR
- SLSTR
- AMSR

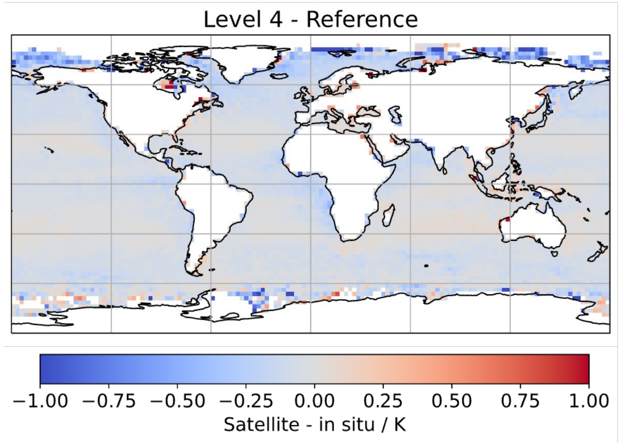
AVHRR GAC

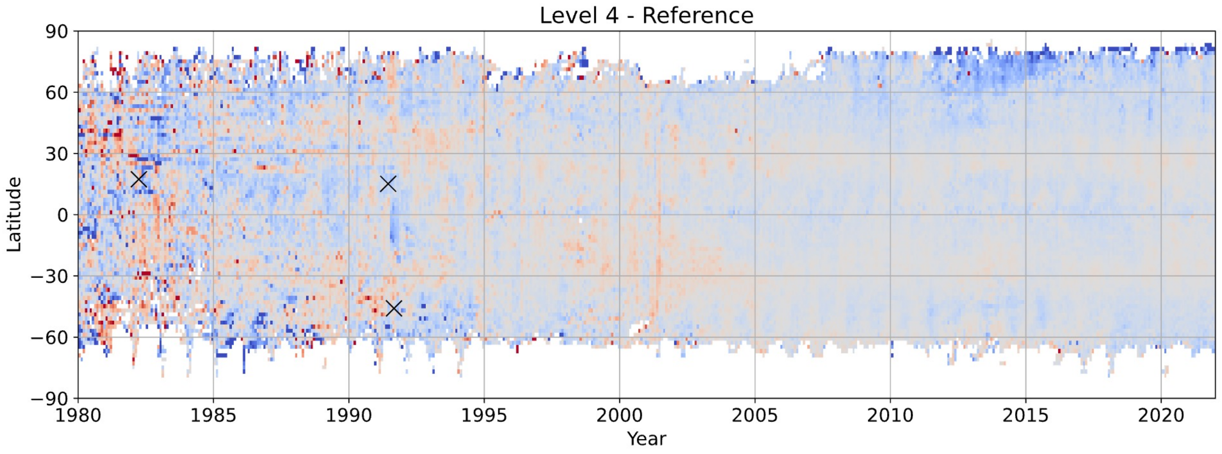
- More data in 1980s / 1990s
- v2 included MetOp as GAC from 2007
- 1980 is NOAA-06 only

Counting QL 4+5

Level 4 Analysis

- Climate configuration of Met Office OSTIA
  - Only uses SST-CCI L2/3 SST inputs – no *in situ*
  - Sea-ice from EUMETSAT OSI-SAF: OSI-450 and OSI-430-b
    - Global Sea Ice Concentration CDR (and ICDR) release 2
  - Analysis is daily-average SST_{20cm}

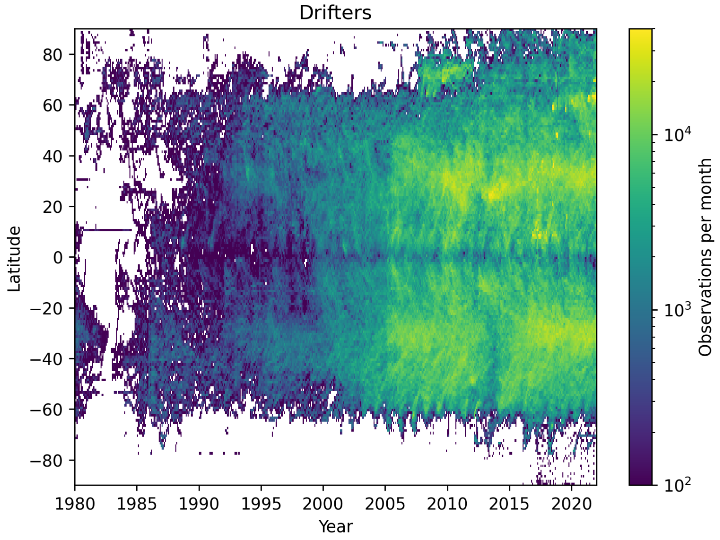




Validation against *in situ*

- SST CCI Independent Reference Data Set (SIRDS)
  - Based on Met Office Hadley Centre Integrated Ocean Dataset (HadIOD)
  - https://www.metoffice.gov.uk/hadobs/hadiod/sirds.html
  - Includes: drifters, gtmba, moorings, ships, argo, bottle, ctd, mbt, xbt, …

- Variable coverage over CDR period
- Ships provide best coverage in 1980s, but highest uncertainty – typically larger than satellite uncertainty
- Drifters provide majority of obs. since early 2000s, but very limited spatial coverage in 1980s
- Main validation results use:
  - All non-ship *in situ* up to 1995
  - Drifters-only from 1995 onwards



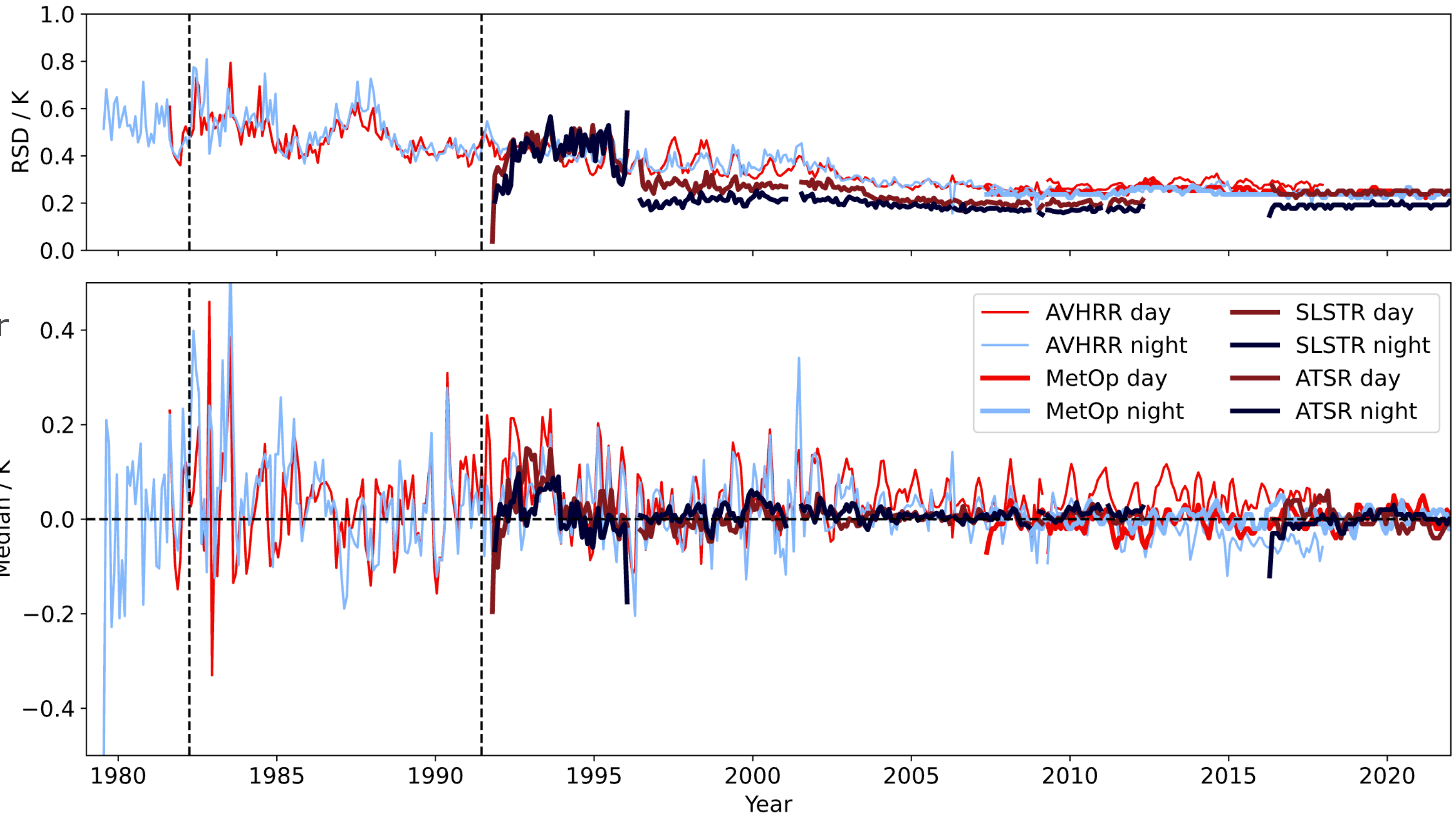
Atkinson et al. 2014, J. Geophys. Res. Oceans, doi:10.1002/2014JC010053

Time series of IR validation against in situ

$SST_{0.2m}$@10:30 compared to *in situ*

- *In situ* includes all non-ship data up to NOAA-12
- Drifters-only used for NOAA-14 onwards.

Vertical dashed lines show time of El Chichón (April 1982) and Mount Pinatubo (June 1991) eruptions.



Summary of IR validation against *in situ*

	Day		Night	
	Median	RSD	Median	RSD
NOAA-06			+0.02	0.55
NOAA-07	+0.00	0.53	+0.07	0.53
NOAA-08			+0.02	0.57
NOAA-09	+0.02	0.49	+0.02	0.51
NOAA-10			-0.04	0.52
NOAA-11	+0.07	0.43	+0.05	0.41
NOAA-12	+0.02	0.40	-0.00	0.41
NOAA-14	+0.04	0.37	+0.02	0.38
NOAA-15	+0.03	0.32	+0.03	0.34
NOAA-16	+0.05	0.30	-0.03	0.29
NOAA-17	+0.07	0.25	+0.06	0.26
NOAA-18	+0.03	0.28	-0.02	0.27
NOAA-19	+0.05	0.28	-0.03	0.25

Reference in situ includes all non-ship data up to NOAA-12

Drifters-only used for NOAA-14 onwards

Summary of IR validation against *in situ*

	Day		Night	
	Median	RSD	Median	RSD
MetOp-A	-0.01	0.25	-0.01	0.24
MetOp-B	+0.01	0.25	+0.02	0.24
ATSR-1	+0.04	0.45	+0.01	0.45
ATSR-1 (d3)			+0.00	0.26
ATSR-2	-0.00	0.28	+0.02	0.21
AATSR	+0.01	0.21	+0.01	0.18
SLSTR-A	+0.02	0.25	+0.00	0.19
SLSTR-B	-0.03	0.24	-0.01	0.19

Uncertainties

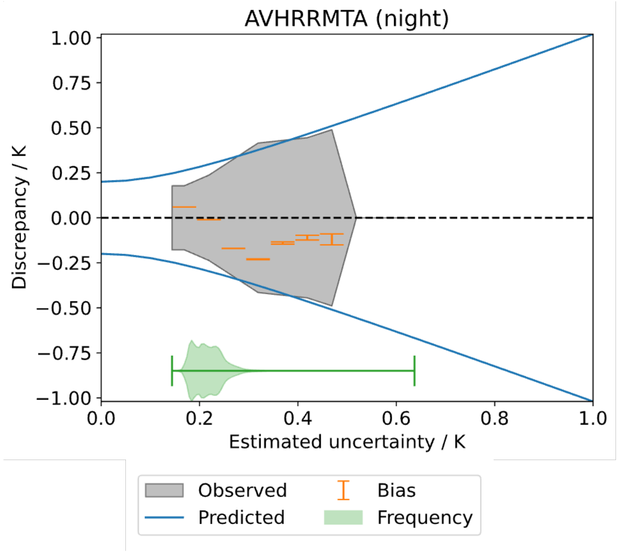
- SST CCI products also include estimates of retrieval uncertainty
- Broken down into components for single-sensor Level 2 / 3 products:
  - **Random** – uncertainty due to effects which are uncorrelated from pixel to pixel (e.g. instrument noise)
  - **Correlated** – uncertainty due to effects which are assumed to be correlated over scales ~100 km / ~1 day (e.g. atmospheric effects)
  - **Adjustment** – uncertainty in the time and depth adjustment

Uncertainty Validation

- Uncertainties can be validated using *in situ* data

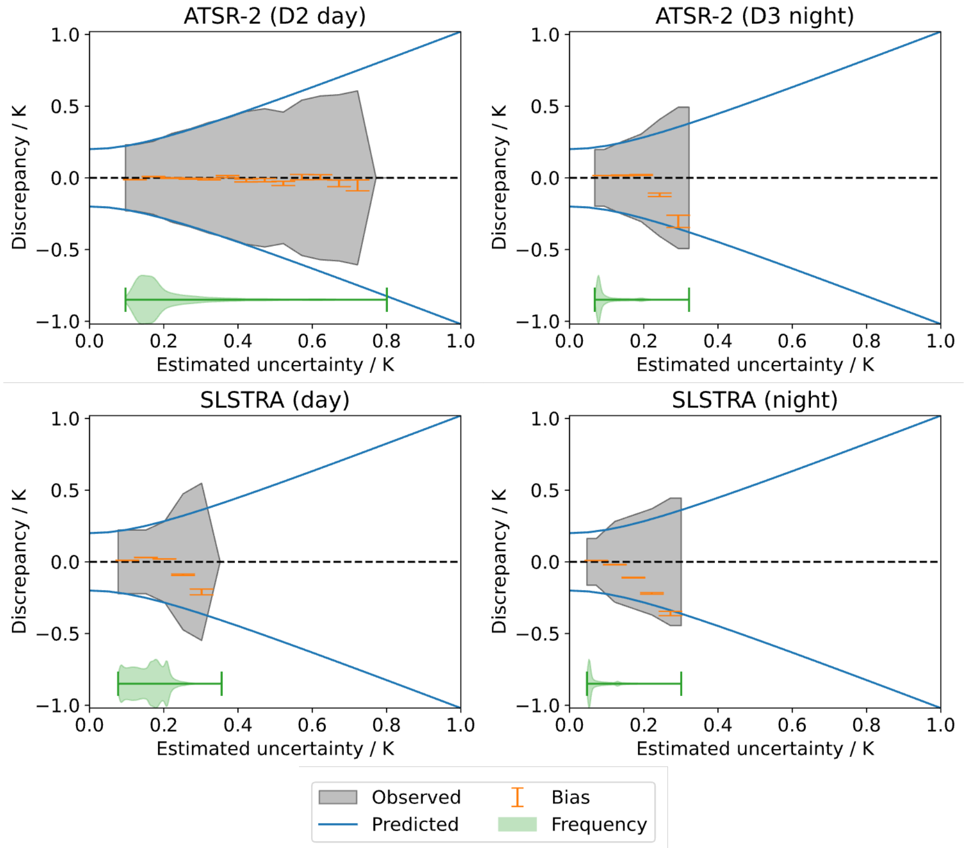
Right: discrepancy (satellite – *in situ*) against estimated uncertainty

- Grey area shows robust standard deviation (RSD) of discrepancy
- Blue line shows expected dependency from assumed *in situ* uncertainty (0.2 K for drifters)
- Green violin plot shows distribution of data



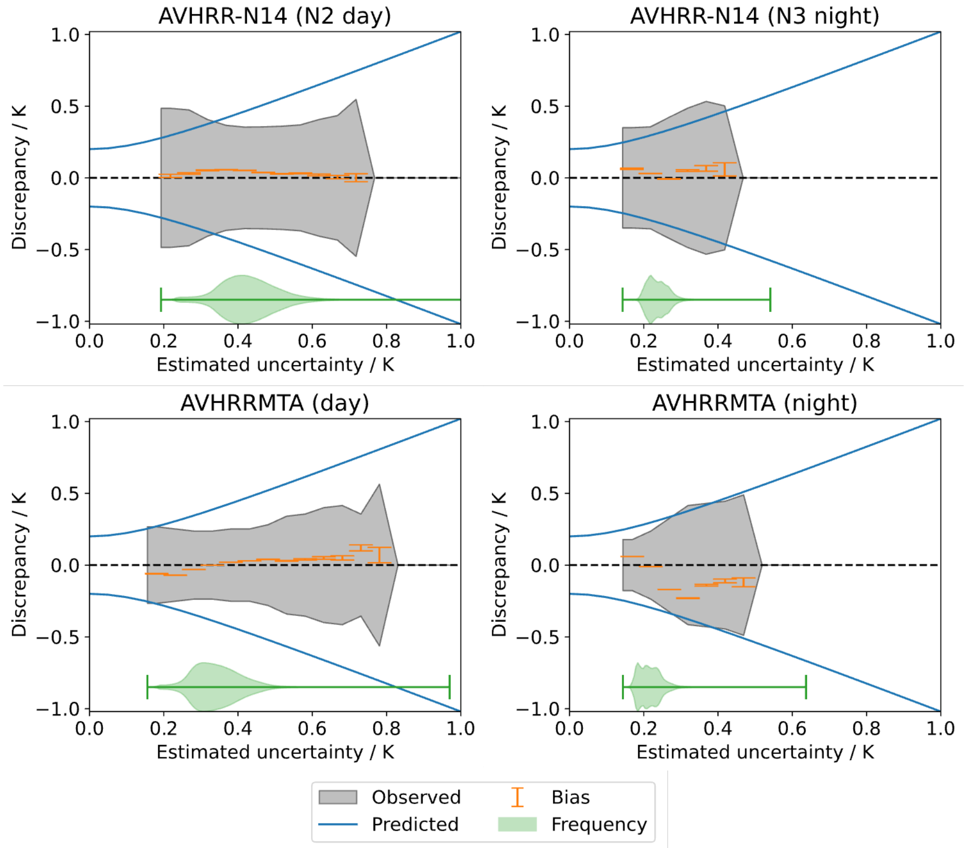
Uncertainty Validation

- Dual-view (ATSR-2 onwards) uncertainties are generally well estimated
- ATSR-1 uncertainties are slightly underestimated
- Largest SLSTR uncertainties are underestimated
- Most SST values have low estimated uncertainties
  - Day ≲ 0.2 K
  - Night ≲ 0.1 K



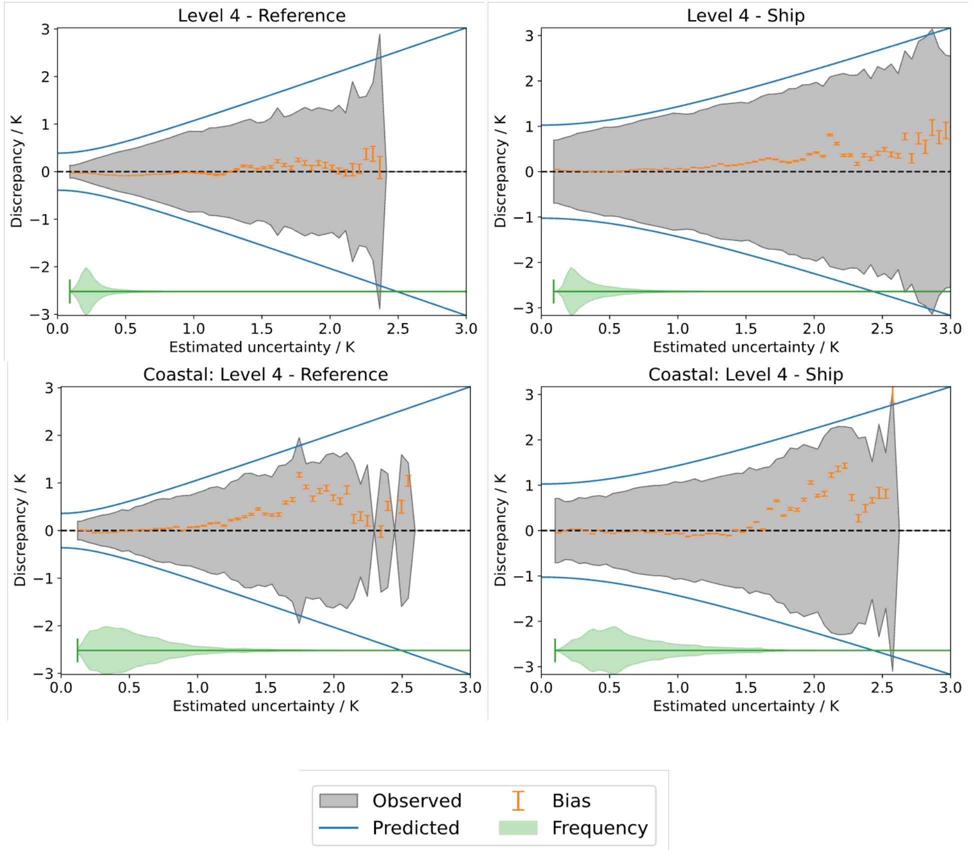
Uncertainty Validation

- Single-view nighttime uncertainties are generally well estimated
- Daytime uncertainty estimates are not skillful



Uncertainty Validation

- Level 4 analysis uncertainty are slightly over-estimated
- Maybe partly related to *in situ* data – reference data had a median reported uncertainty of 0.39 K
- Majority of data have estimated uncertainty < 0.5 K
- Data are more uncertain in coastal regions



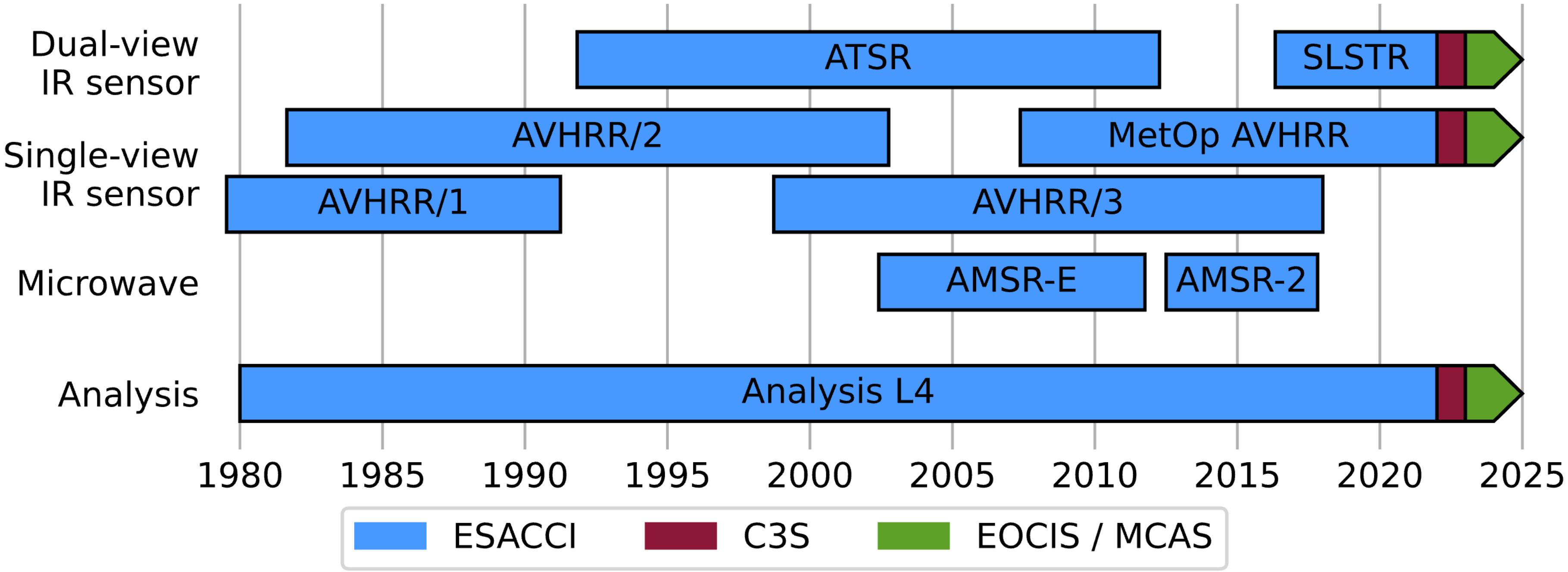
Interim-CDR

- Ongoing extension of SST-CCI CDR produced using the same software
  - Uses ECMWF ERA5-T as prior rather than ERA5 (CDR)
  - 2-3 weeks behind present

- With version 3 both CDR and ICDR will be accessed as a single dataset via CEDA

- 2022 funded by Copernicus Climate Change Service (C3S)
- 2023 onwards funded by:
  - UK Earth Observation Climate Information Service (EOCIS) – Level 2/3 production (Reading)
  - Marine Climate Advisory Service (MCAS) – Level 4 production (Met Office)

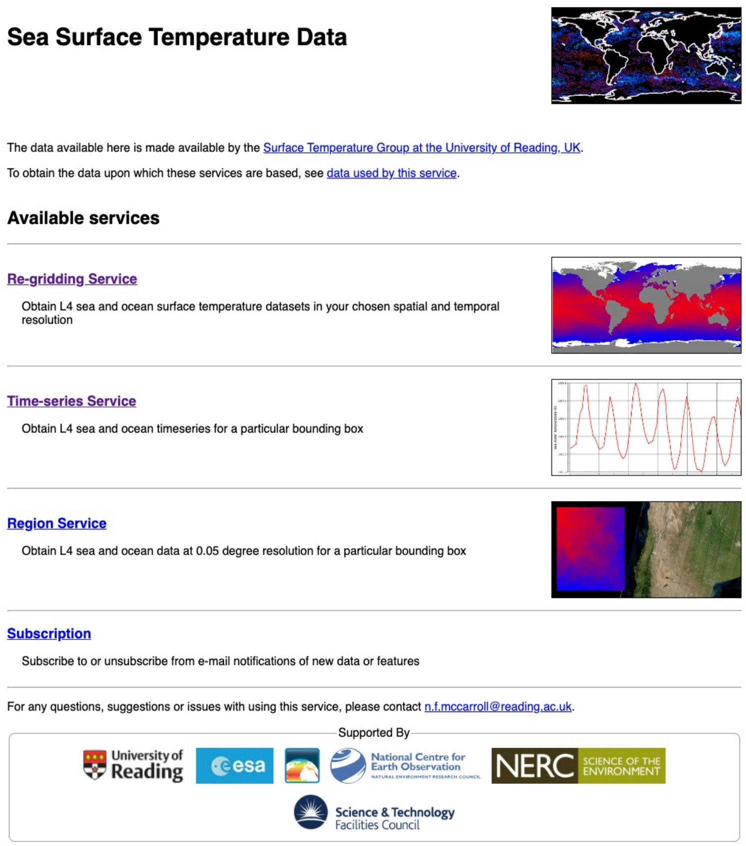
Interim-CDR



Dual-view IR sensor
Single-view IR sensor
Microwave
Analysis
ATSR
SLSTR
AVHRR/2
MetOp AVHRR
AVHRR/1
AVHRR/3
AMSR-E
AMSR-2
Analysis L4
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
ESACCI
C3S
EOCIS / MCAS

Surftemp.net

- Steady stream of requests from users with less compute capability to deal with full SST CCI archive data on CEDA
- For flexible low-resolution and extraction requests: https://surftemp.net/
- Region, time period and resolution requested are ordered, and users download from a link after creation
- Regridded uncertainties are also estimated
- Made under NCEO funding
- 77 subscribed users plus many anonymous



Sea Surface Temperature Data

The data available here is made available by the Surface Temperature Group at the University of Reading, UK.

To obtain the data upon which these services are based, see data used by this service.

Available services

Re-gridding Service

Obtain L4 sea and ocean surface temperature datasets in your chosen spatial and temporal resolution

Time-series Service

Obtain L4 sea and ocean timeseries for a particular bounding box

Region Service

Obtain L4 sea and ocean data at 0.05 degree resolution for a particular bounding box

Subscription

Subscribe to or unsubscribe from e-mail notifications of new data or features

For any questions, suggestions or issues with using this service, please contact n.f.mccarroll@reading.ac.uk.

Supported By

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Intercomparison: Recent Warming

CMC

- ICOADS (GTS from 2007) Ship + Buoy
- NAVO AVHRR
- REMSS: TMI, Windsat, AMSRE, AMSR2
- OSPO VIIRS
- EUR ATSR

DOISST

- ICOADS (GTS for 2007-2016) Ship + Buoy
- Argo from 2016 onwards
- 1981-2006: AVHRR Pathfinder
- 2007-2021: NAVO AVHRR
- 2021-onwards ACSPO MetOp-B + VIIRS

OSTIA Reprocessing 2.0

- HadIOD Buoy
- ESA CCI v2.1: AVHRR, ATSR, SLSTR
- REMSS: TMI, GMI, AMSRE, AMSR2
- OSI-SAF: GOES-13, GOES-16, SEVIRI

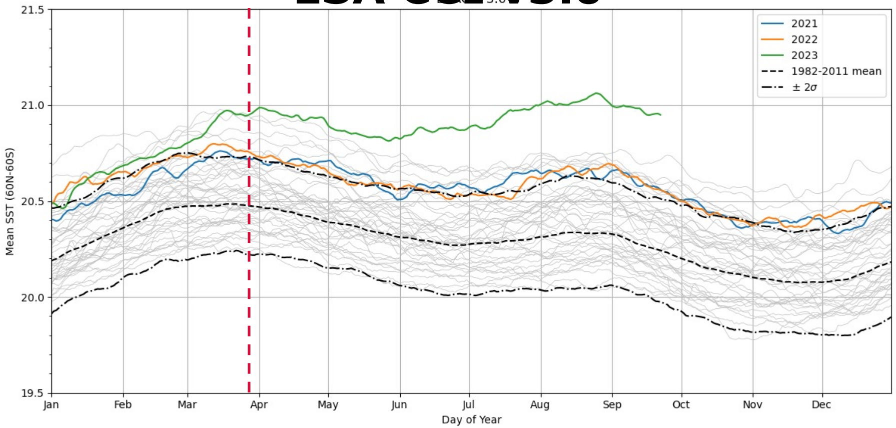
OSTIA 2.0 analysis combines ESA CCI v2.1 L2/3 with other satellite and in situ to produce a foundation SST

- not the same as CCI Analysis SST 2.1

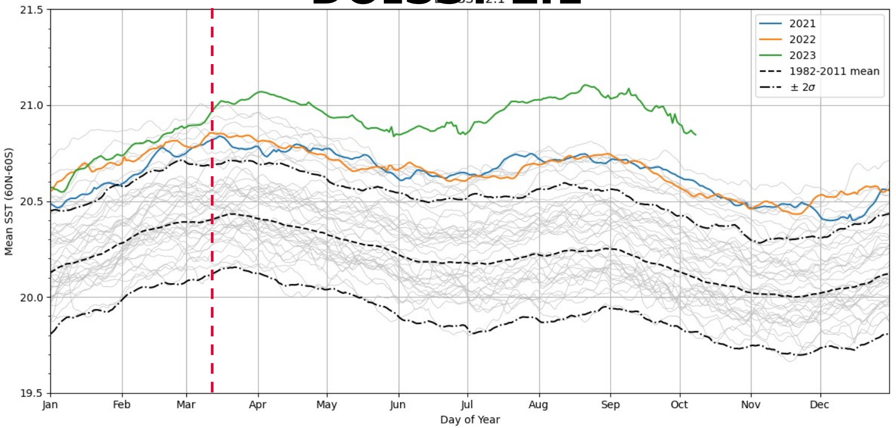
DOISST is only product to include Argo

Intercomparison: Recent Warming

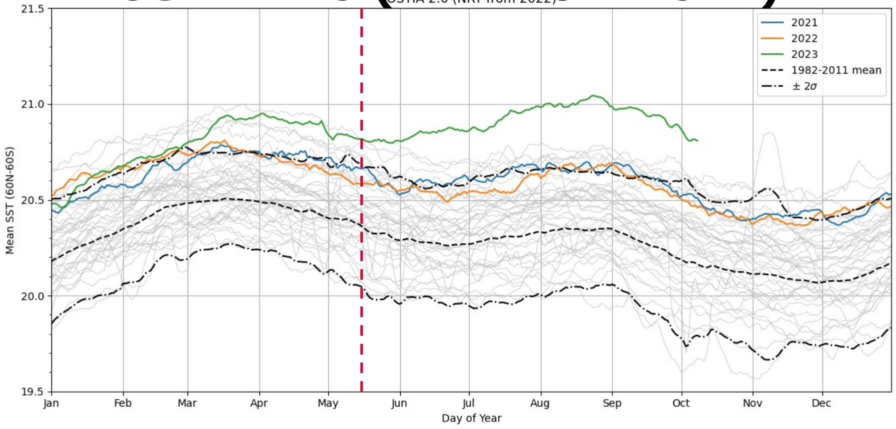
ESA CCI v3.0



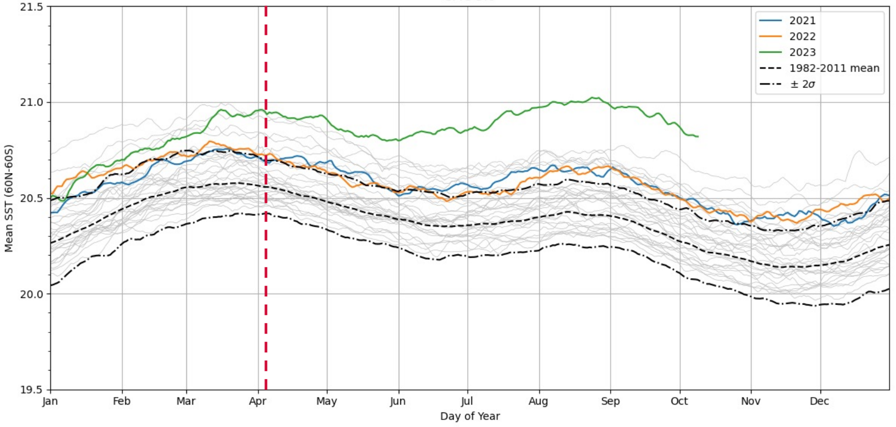
DOISST 2.1



OSTIA 2.0 (NRT from 2022)



CMC



Intercomparison

CMC

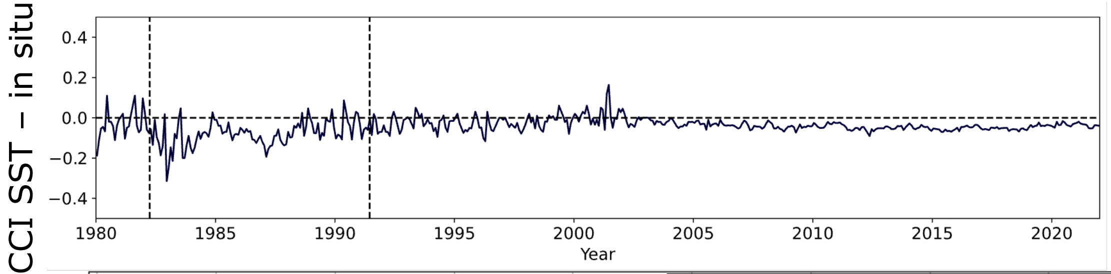
- ~0.15 K trend from 1991 to 2000
- match within 0.05 K from ~2002

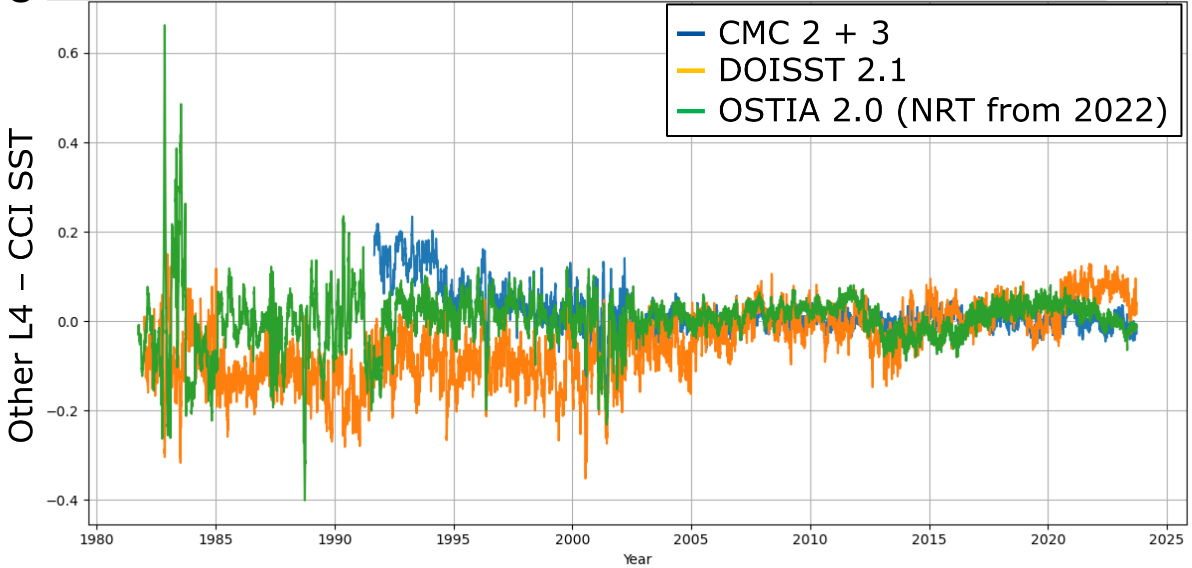
DOISST

- ~0.1 K cooler in 1980/90
- 0.1 K step change in 2020

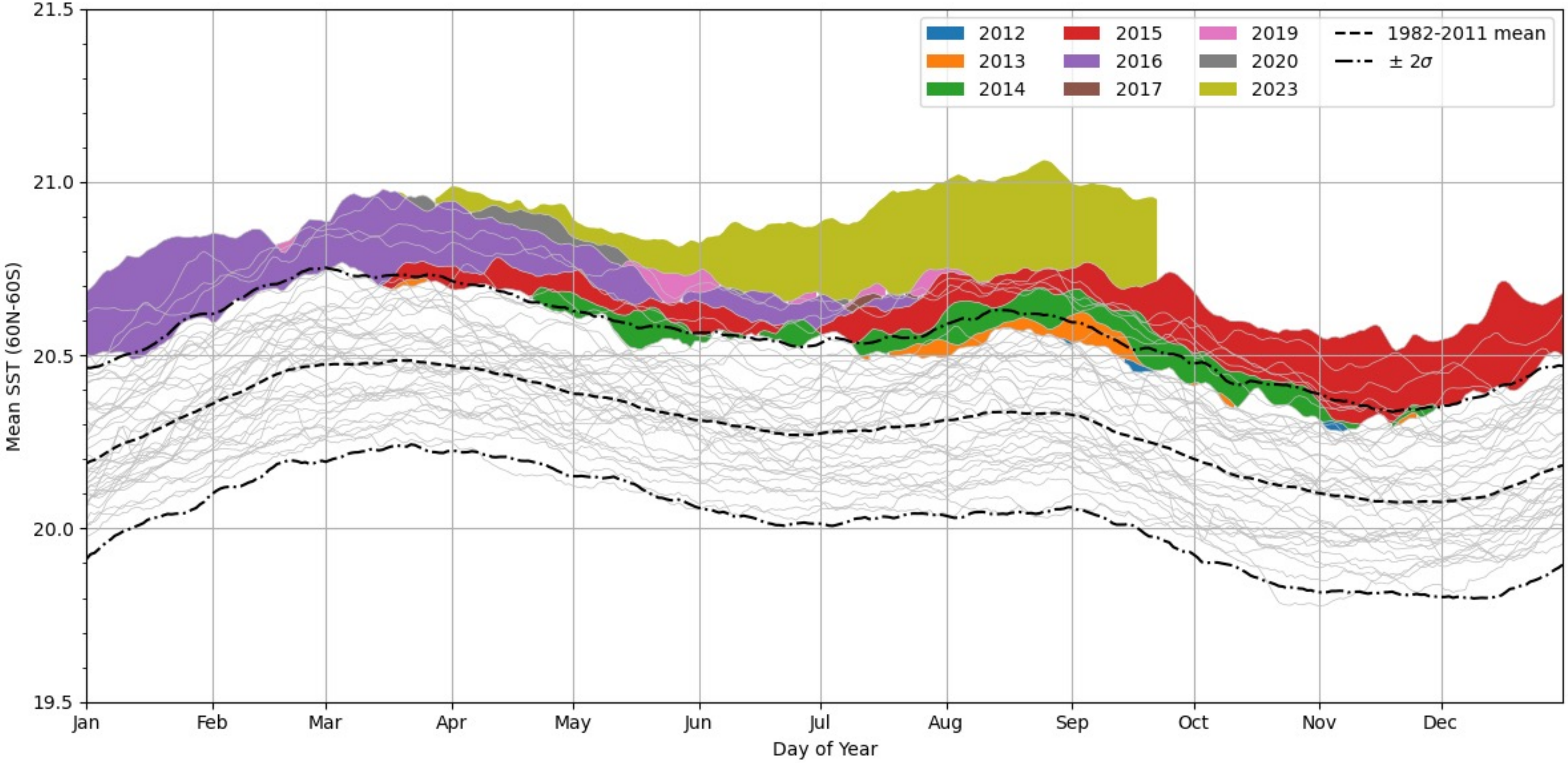
OSTIA

- Dual-view gap 2012-2017
- Includes NRT from 2022

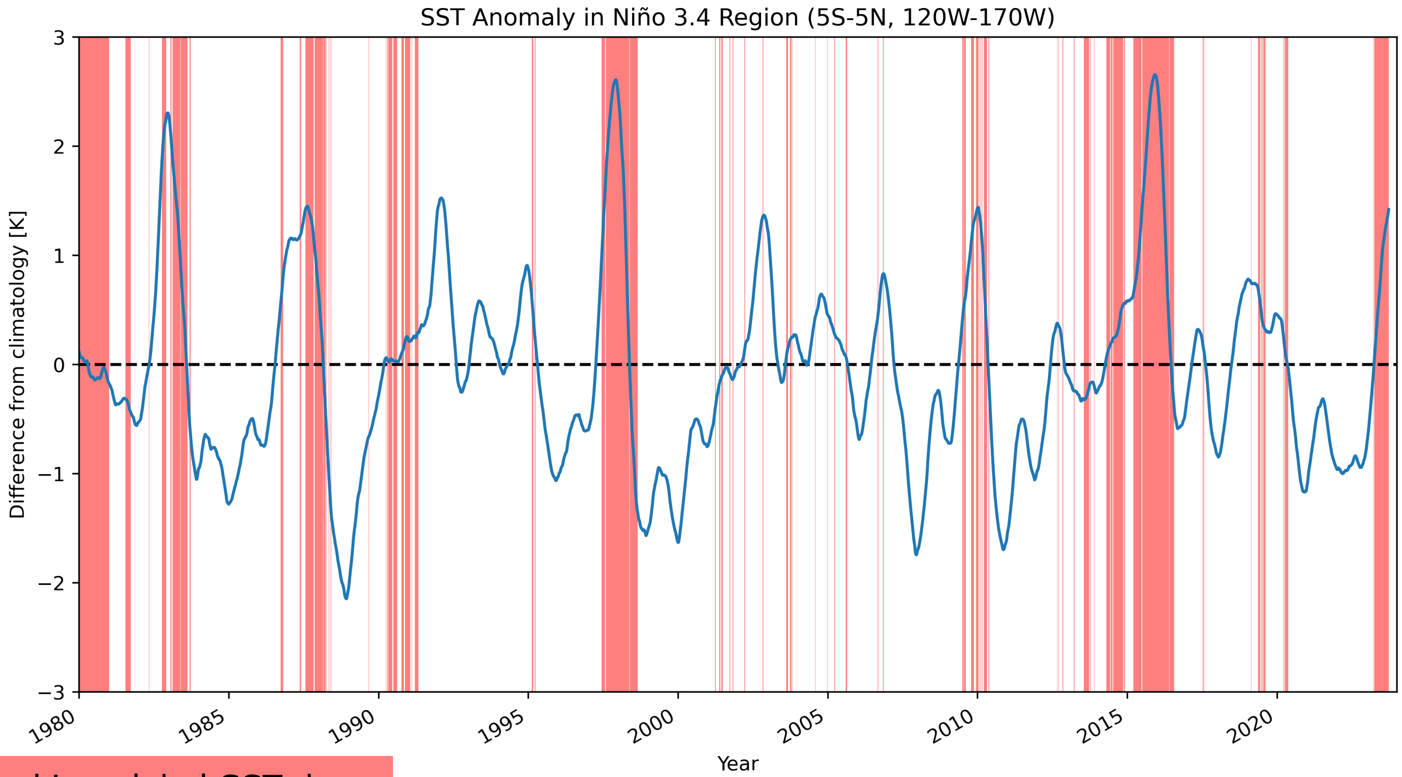




Mean Global SST (ESA CCI v3.0)



ENSO 3.4 index



Record-breaking global SST days

Summary

- 42-year CDR from 1980 to end-2021
  - Adds AVHRR/1, Passive Microwave, full-resolution MetOp, and SLSTR
  - New bias-aware OE retrieval and reduced desert-dust related biases

- Interim-CDR to provide ongoing extension at 2-3 weeks latency
  - 2022: C3S
  - 2023 onwards: UK funding EOCIS / MCAS

- Public data release will be late 2023 via the CCI Open Data Portal
  - https://climate.esa.int/en/odp/
- Regional and re-gridded data products:
  - https://surftemp.net/