European Space Agency Climate Change Initiative

Sea Surface Temperature **www.esa-sst-cci.org**

SST Climate Change Initiative ATSR and AVHRR harmonisation

Chris Merchant, Owen Embury & the SST CCI Team

presented by Hugh Kelliher

Ambitions for SST CCI

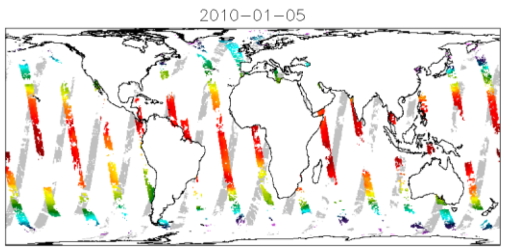
An independent time series of SST that has sufficient length, uncertainty and stability to provide improved quantification of SST variability and change

Target characteristics

- Independence
  - based on physics of radiative transfer and harmonisation, not dependent empirical tuning to other SST measurements
- Covering at least 1983 to 2016 (target, 1981)
  - includes the particular challenge of the El Chichon and Pinatubo/Hudson periods
- High stability, high SST sensitivity, and low bias
- Integrated processing across levels 2 to 4 (swath, gridded and analysis)
- Uncertainty-quantified at all levels
- Skin SST (core retrieval) and 20-cm daily average estimates (model)

Requirement	GCOS (2016)	SST CCI URD L3/L4 breakthrough'	SST CCI Ph 1 result (v2.0)	SST CCI Ph2 target (v2.1) (1 sigma)
Uncertainty / demonstrated on scale	0.1 K / 100 km	0.02 K / 100 km	Generally ~0.2 K / regionally	0.1 K / 1000 km ATSR era, 0.2 K 1980s.
Stability (retrospectively assessable against tropical moorings only, using current methods)	0.03 K / decade	0.02 K per decade; 0.05 K seasonally, diurnally	Mostly <0.05 K per decade for 1996 – 2010; seasonal stability generally ~0.2 K, locally greater	<0.05 K per decade for 1991 to present; ~0.1 K / decade overall
Spatial resolution	1 km to 100 km	0.1 deg	0.05 deg	0.05 deg
Temporal resolution	Hourly to weekly	Day/night (UTC)	Day/night on standardized local time (L2, L3); daily (L4)	Day/night SST (L2/L3) Daily mean (all levels)
Uncertainty information	--	Total uncertainty	Total and components	Total and components, corr. length scales
Type of SST	Blended	Skin & buoy-depth	Skin and buoy-depth	Skin and buoy-depth
Period	--	~1980 - now	1991 - 2010	1981 - 2016

Sea Surface Temperature CCI



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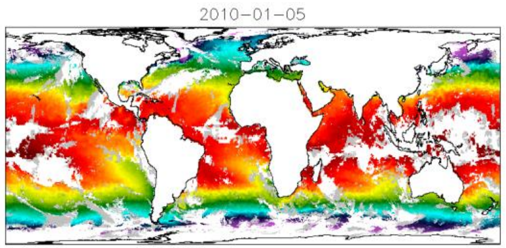

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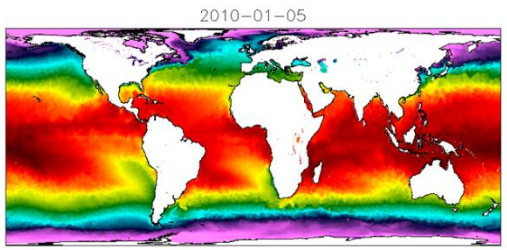
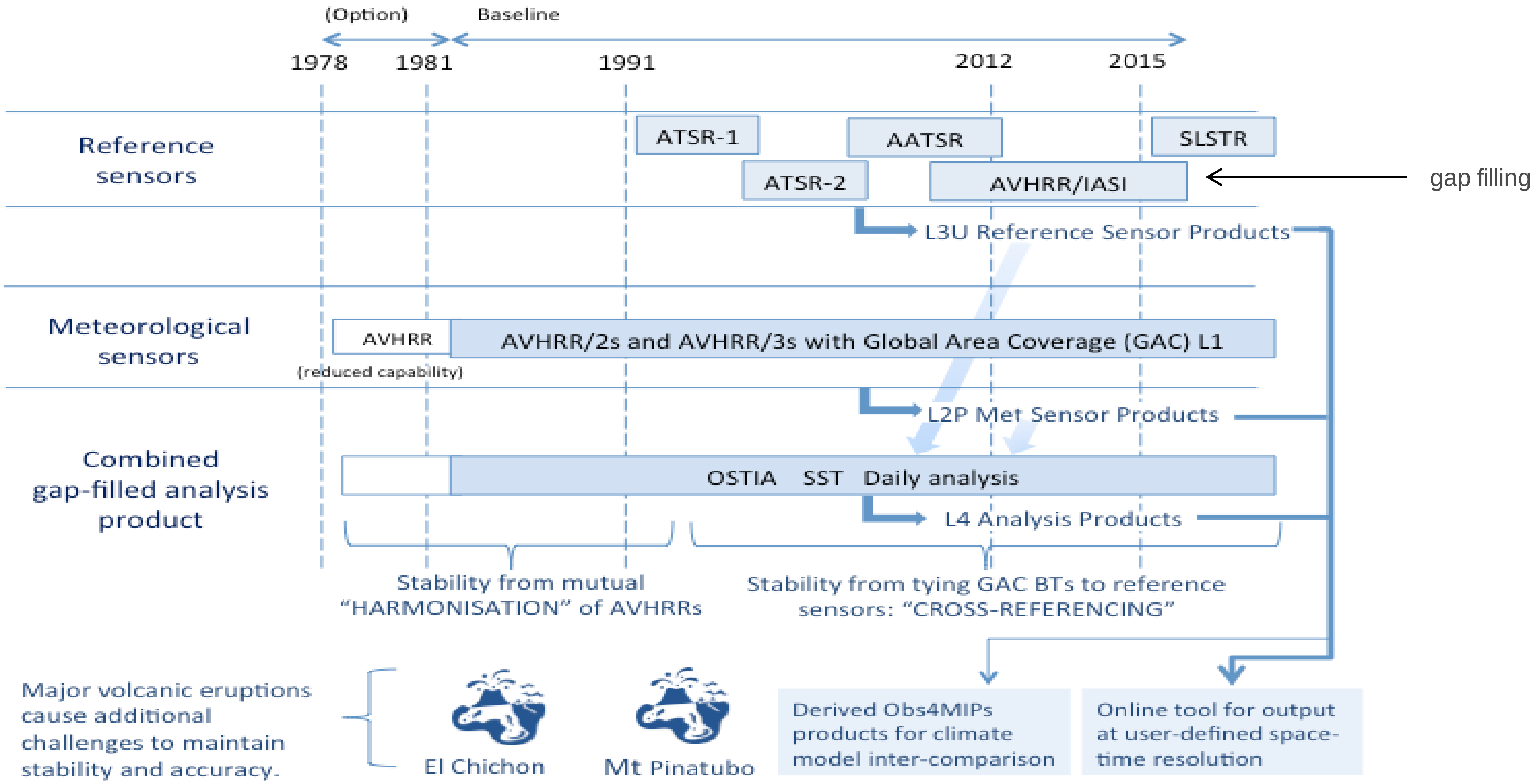


ATSRs: dual view, **stable** & **accurate**. Use as SST calibration reference.

AVHRRs: single view, not designed for climate, **good coverage** and a **longer history**.

ATSRs & AVHRRs are blended using an improved version of Met Office “OSTIA”.

~35 year uncertainty-quantified SST CDR
Integrated, consistent L2, L3 & L4



ESA · University of Reading · Met Office · Brockmann Consult · DMI · Norwegian Meteorological Institute · Meteo France (Toujours un temps d'avance) · University of Leicester · Space ConneXions · National Oceanography Centre (Natural Environment Research Council)

Methods for retrieving SST

Retrieval coefficients

$$x = a_0 + \mathbf{a}^{\mathrm{T}}\mathbf{y}$$

Used for dual view SSTs

- **ATSRs**

Fixed coefficients derived by
off-line radiative transfer

- Harmonised along series of ATSRs

Made “robust” to volcanic aerosol by finding coefficients, **a**, that

- minimize SST error variance in non-SAOD conditions
- subject to the constraint $\mathbf{a}^{\mathrm{T}}\mathbf{k} = 0$

(**k** is the inter-channel SAOD impact)

Optimal estimation

$$\mathbf{z} = \mathbf{z}_a + \mathbf{S}_a\mathbf{K}^{\mathrm{T}}\left(\mathbf{K}\mathbf{S}_a\mathbf{K}^{\mathrm{T}} + \mathbf{S}_\epsilon\right)^{-1}\left(\mathbf{y} - \mathbf{F}(\mathbf{x}_a)\right)$$

Used for single-view SSTs

- **AVHRRs**
- Because there is insufficient real information content in 2 window channels without some prior constraint

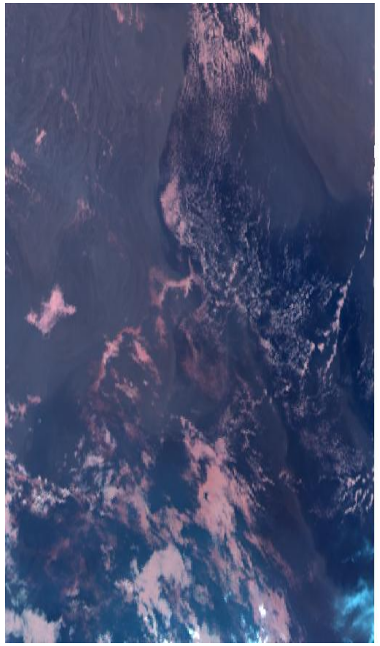
In-line fast radiative transfer

Need prior volcanic aerosol and uncertainty

- Derived from ATSR-1 and HIRS datasets

SST CCI cloud detection: Bayesian

NWP ANALYSIS + UNCERTAINTIES



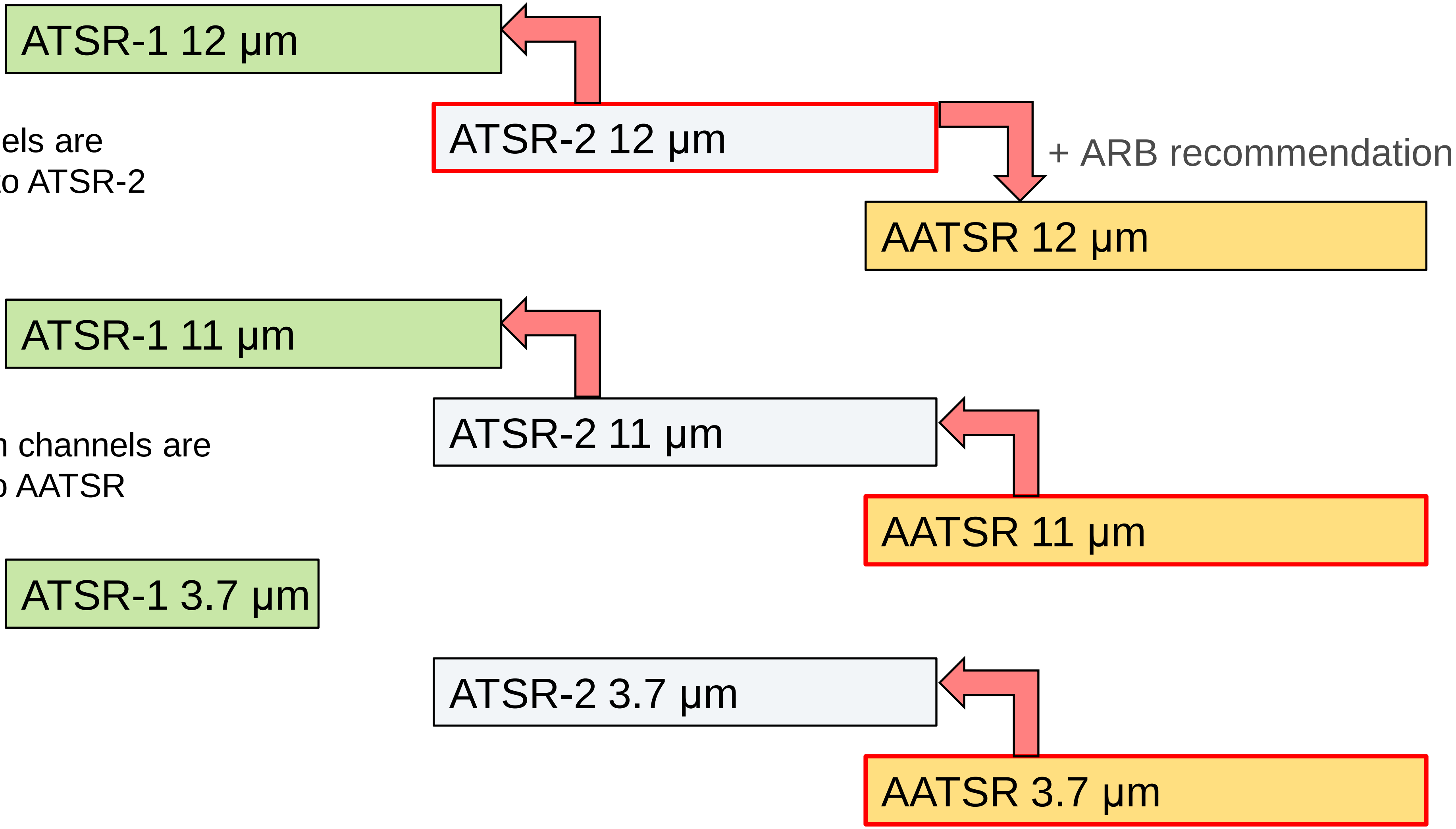
Imagery

Bayes' Theorem

Mask on P

FORWARD MODEL FOR SENSOR + UNCERTAINTIES

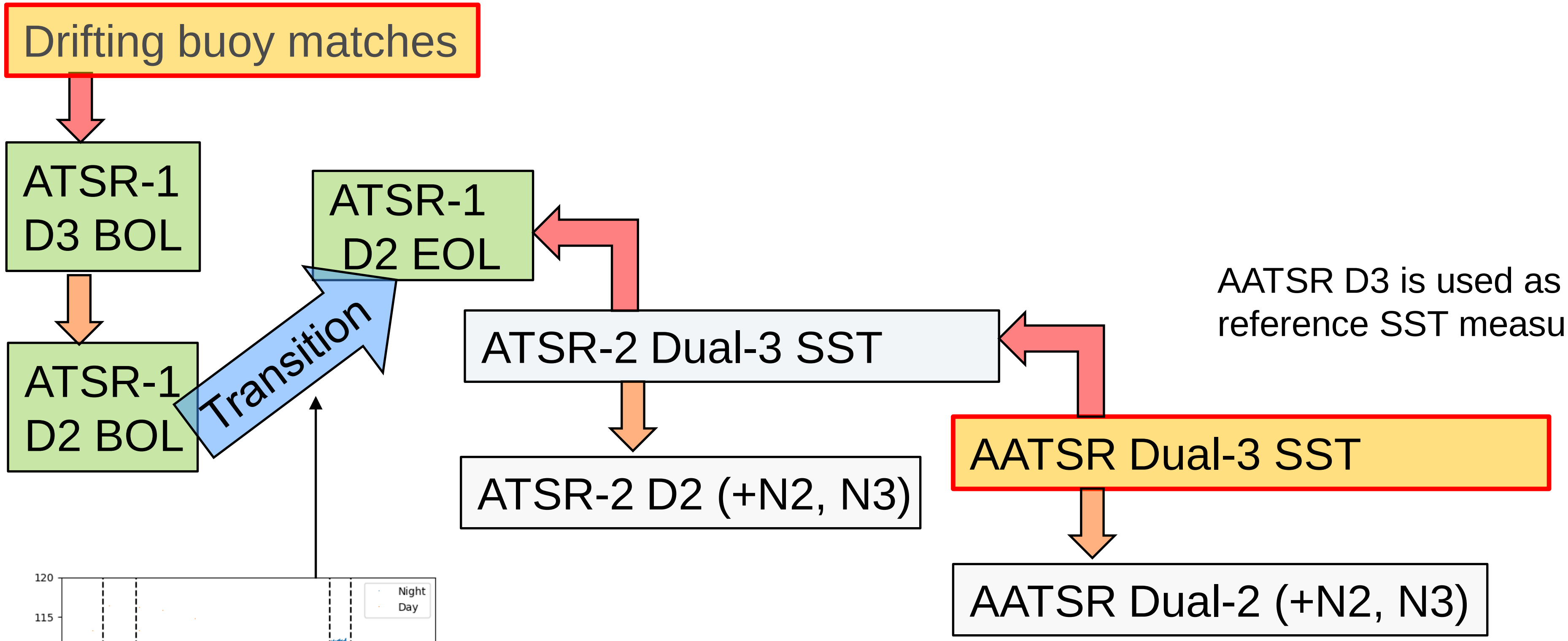
ATSR-series BT harmonisation concept



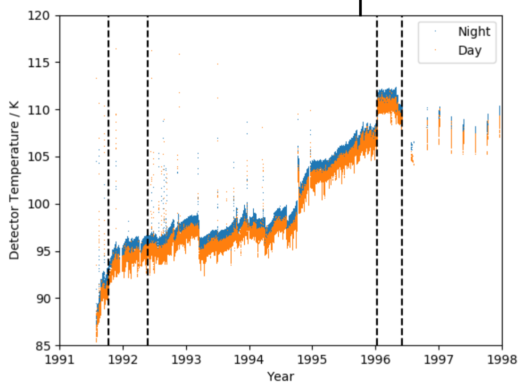
12 µm channels are harmonised to ATSR-2

3.7 and 11 µm channels are harmonised to AATSR

SST harmonisation logic



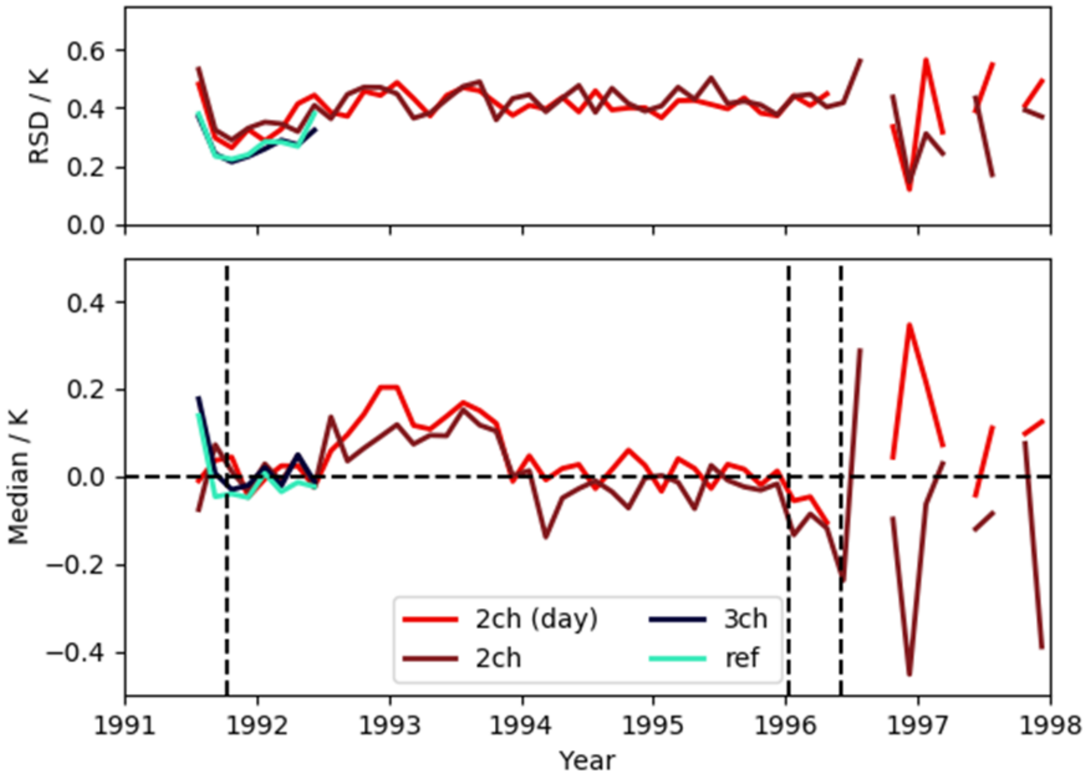
AATSR D3 is used as the reference SST measurement



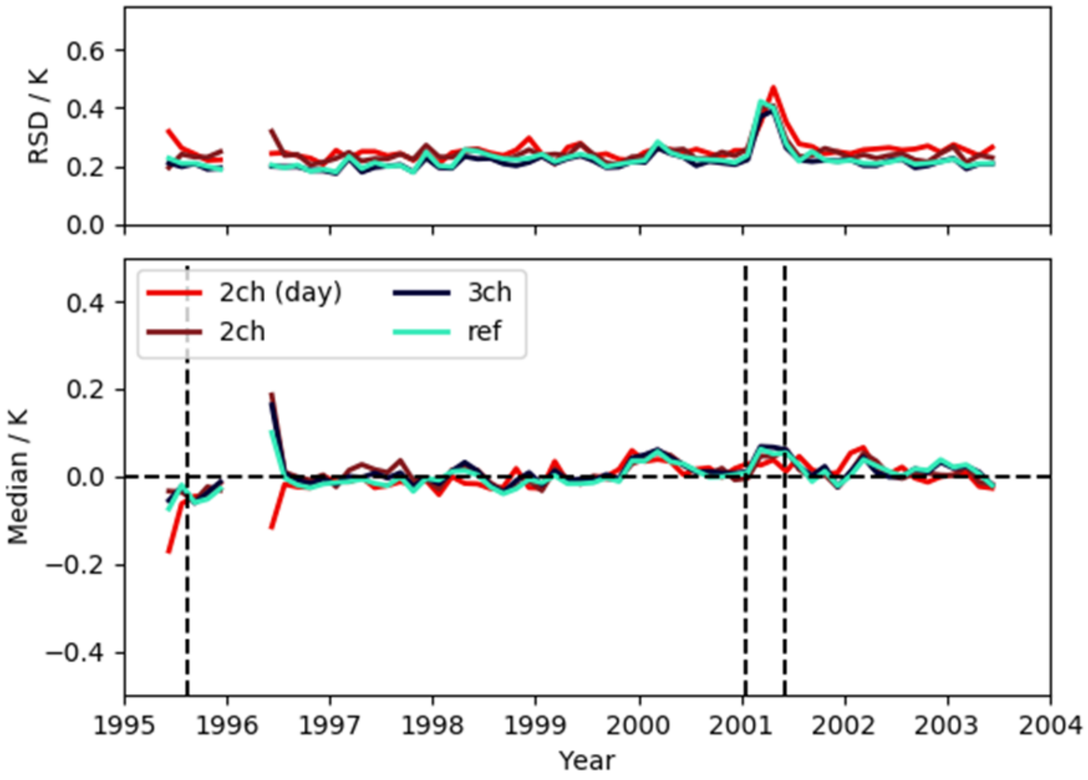
ATSR-1 Detector temperature trend

ATSR – drifter

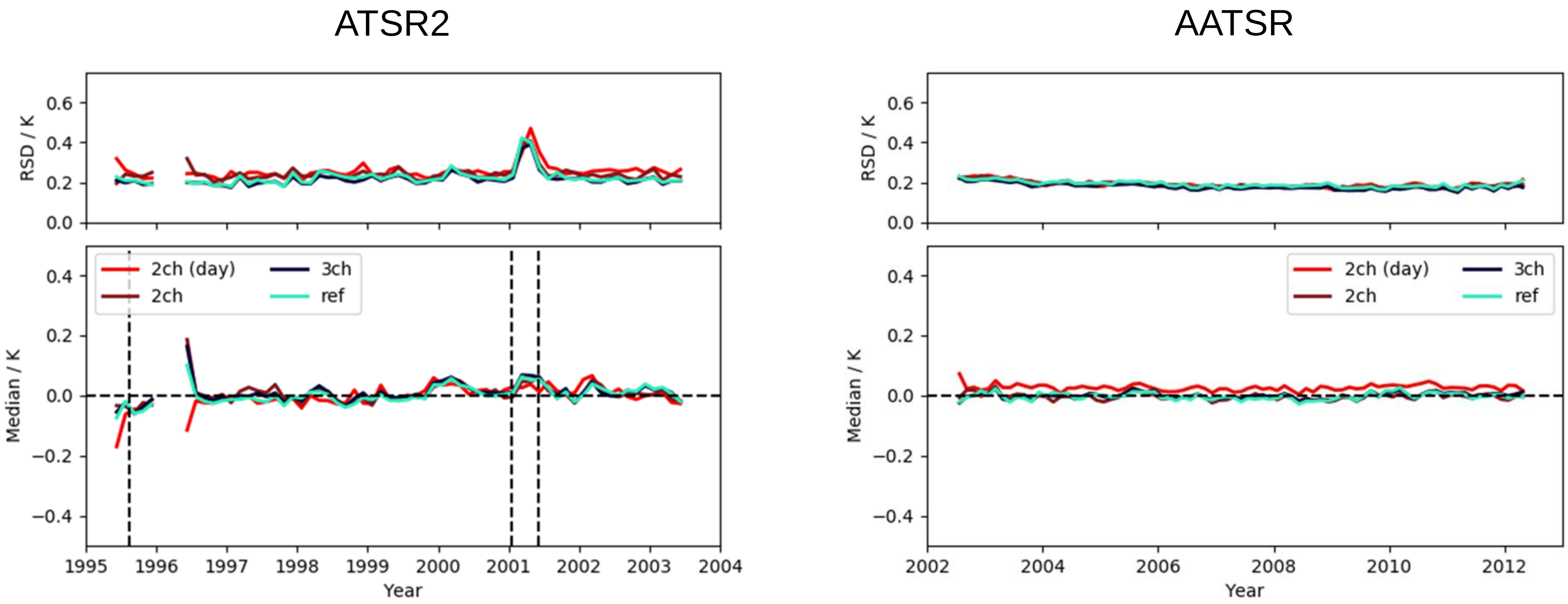
ATSR1



ATSR2



ATSR – drifter



ATSR SST Harmonisation

Harmonise BTs between sensors:

- 3.7 µm: Failed early on ATSR1 so no overlap
- 11 µm: Harmonise to AATSR
- 12 µm: Known issue on AATSR, so harmonise to ATSR2

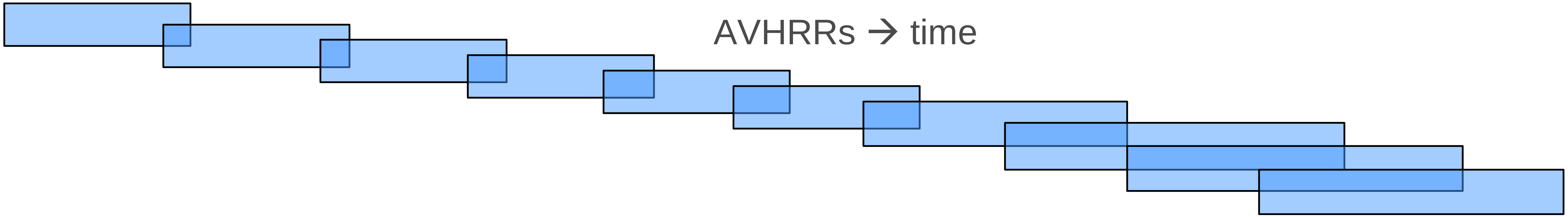
BT harmonisation addresses inter-satellite, but not intra-satellite

- Biases between different channel combinations (e.g. 2-channel nadir vs. 3-channel dual view)
- Harmonise SSTs between channel combinations (D3 used as 'reference' retrieval)

ATSR1 is least stable (operated at elevated temperature) and 3.7 µm is not harmonised

- Need to tie to in situ data at beginning of life

AVHRR harmonisation



Brightness temperature harmonisation:

Cross-calibrated with ATSR-2 and AATSR

Calibration chained back

SST harmonisation:

Pre ~1995 – with reference to drifting buoys.

Post ~1995 – with reference to ATSR-2/AATSR/Metop-A

AVHRR Calibration issues and corrections

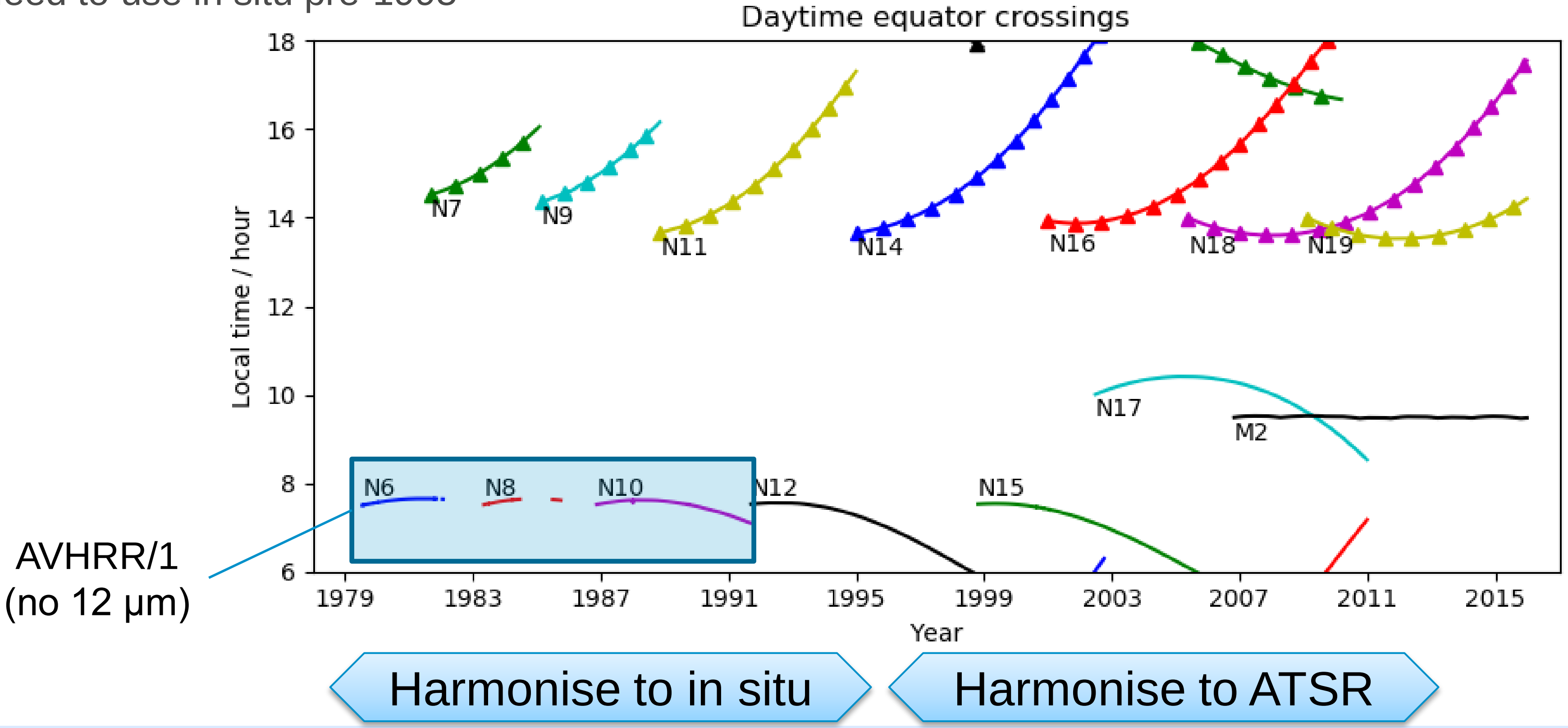
- The AVHRR Level 1B data as produced by NOAA have a lot of calibration biases in both the visible and IR channels
- In CCI we have put in place procedures to reduce these biases
  - All calibration data are filtered for outliers
  - Visible channel
    - Calibration based on CSPP (Univ. of Wisconsin) with time dependent coefficients
  - IR channels
    - All fundamentally based on a consistent calibration (Walton et al. 1998) unlike the operational calibration
    - Four sources of error (three major) still exist in Walton calibration which have to be modelled
      - Direct solar contamination of the internal calibration target (blackbody) in the 3.7µm channel
      - Stray light effects plus orbit drift effects give rise to a strong time dependent bias in the observed radiance
      - Error in relating the four PRT measurements on the internal calibration target (ICT) to the radiant temperature of the ICT
      - Scene temperature dependent bias due to errors in Walton et al. calibration.(smaller – a few 10ths)
        - Use average trend from (A)ATSR vs AVHRR double differences for all AVHRRs
    - Preliminary models exist of all effects and are being implemented in the Level 1B reader
    - Finalising interplay between all effects for final radiance at the moment

AVHRR SST Harmonisation

SST harmonisation applied after BT calibration / harmonisation

Calculate SST bias relative to reference as function of TCWV, time, angle, etc.

- ATSR2/AATSR for post-1995
- Need to use in situ pre-1995



How SST CCI is addressing users needs for CDR?

- Integrating data from many satellites using consistent approaches
- Processing from level 2 to 4 in a co-ordinated approach
- Maximising independence from in situ observations in the era where satellite references are available, by using physics-based approaches
- Emphasising stability through harmonising at level 1 and level 2 (as far as possible: improved level 1 harmonisation is coming via FIDUCEO for AVHRRs)
- Dealing with near-surface stratification and skin effects so as to make satellite products as compatible as possible with the centennial scale records
- Aiming to exclude aliasing of diurnal variability into long term trends
- Providing uncertainty information at all product levels

Bridging the Gap between AATSR and SLSTR

Chris Merchant, Owen Embury & the SST CCI Team

presented by Hugh Kelliher

Linking AATSR and SLSTR

- Metop-A is a key sensor to link AATSR to SLSTR
  - In Phase II, we have exploited Metop-A GAC (low res) and EUMETSAT (hi res) – but the re-calibration work only can be applied to GAC
  - However, because of cloud detection advantages, we really want to use Metop-A FRAC to link, where we have both hi res and can re-calibrate
  - Metop-A also benefits from IASI on the same platform
- Approach
  - Make SLSTR-AVHRR_A-IASI and AATSR-AVHRR_A-IASI match-up datasets (MMDs)
  - Add radiative transfer and synthesis of SLSTR and AATSR from IASI
  - Assess SLSTR-AATSR calibration differences mediated by AVHRR_A and by IASI
  - Develop interpretation and define gap bridging method suitable for nest phase of CCI (CCI+)
- Outputs
  - MMS reading tools and datasets.
  - Harmonisation methodology for AATSR-SLSTR and associated draft paper

Preliminary conclusions

- Given our experience with SLSTR so far, and comparisons with IASI, SLSTR has as much credibility as a reference sensor as AATSR (and for the 12 µm channel, SLSTR is probably more secure).
- We don’t therefore want to adjust SLSTR to AATSR or vice versa -- bridging is about tying the sensors that fill the gap to both AATSR and SLSTR at either end and temporally infilling across the gap.
- Comparison with in situ measurements, including data such as ships4SST, give the confidence that this gives a satisfactory outcome.

Towards a v3.0 SST dataset

We expect v2.0/v2.1 will not meet our targets and user requirements in some regards:

- SST stability in the 1980 to 1995 unlikely to meet GCOS 0.03 K/dec
  - Volcanic aerosol events (1982 and 1991) accounted for but relatively immature for AVHRRs
  - FIDUCEO-style harmonisation of calibration will happen after v2.0, and should be an available improvement
  - Both of the above can be improved by additionally exploiting the HIRS instruments (new FCDR coming from FIDUCEO)
    - Independent retrieval of IR AOD from volcanic aerosol events
    - Additional constraints on AVHRR stability by looking at AVHRR-HIRS differences over time

Towards a v3.0 SST dataset

We expect v2.0/v2.1 will not meet our targets and user requirements in some regards:

- GAC cloud detection needs improvement for CDR, despite progress made relative to CLAVR-X or EUMETSAT
  - Harmonised records will help next time
  - Could HIRS also help here?
  - Forward model for coastal zone reflectance

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Bayesian Cloud Detection for 37 Years of Advanced Very High Resolution Radiometer (AVHRR) Global Area Coverage (GAC) Data

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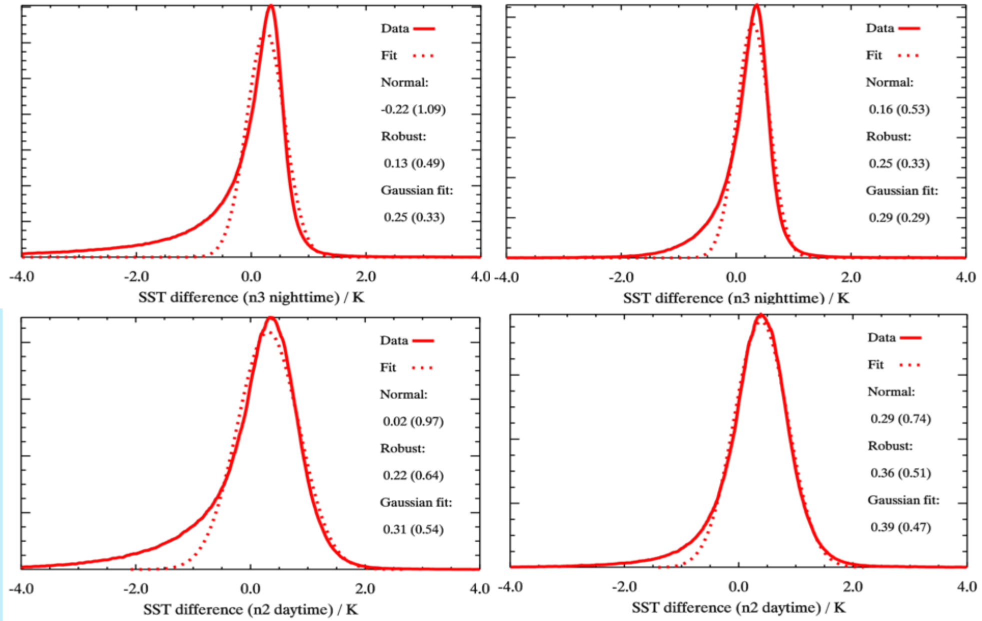

Towards a v3.0 SST dataset

We expect v2.0/v2.1 will not meet our targets and user requirements in some regards:

- Biases from mineral aerosol such as Saharan Dust >>0.1 K
  - No accommodation of such dust in the state vector used for AVHRR (OE)
  - Time-series of hourly Saharan Dust Index now created by Meteo-France, but too late to be exploited for v2.0
    - Need to add to MMS system as a diagnostic to learn how to include this aerosol in the state vector and retrieve SST with less bias (aim for reduction by an order of magnitude)
    - Consider using product (with added value processing) as prior information
    - Need also to process this to a Saharan Dust climatology for use pre-SEVIRI
  - Need also to assess MW impact in dust areas (but this won't help pre 1998)

Towards v3.0

Other desirable / plausible tasks:

- Implement, test, improve, deploy AATSR-to-SLSTR stability method from bridging work
- Bring in SLSTR A and B in due course (this can learn from S3 MPC and outcomes of Tandem phase studies)
- Depending on assessment of microwave CDR work, may be able to introduce MW into the CDR without compromising stability
- L4 analysis development (at least keep step with best techniques)

Final Thoughts

- CCI+ will be the only programme internationally doing R&D on the long-term SST satellite record, since US Pathfinder has apparently ceased R&D and FIDUCEO will be ended next year.
- Our USP is the 35+ year aspect, implying priority for
  - Maximising the value gained over the 1979 to 1995 period
    - Improved retrievals with respect to aerosols (mineral and stratospheric), stability, cloud detection, including by maximising additional constraints from HIRS
  - Pulling the AATSR-to-SLSTR work through from the bridging work to CDR