Sea Surface Temperature as an Essential Climate Variable

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GlobColour / Medspiration Workshop, 19-20 November 2008, ESRIN, Frascati.

Essential Climate Variables

- SST is one of these 44 + 6 parameters
- Identified as essential to support UNFCCC

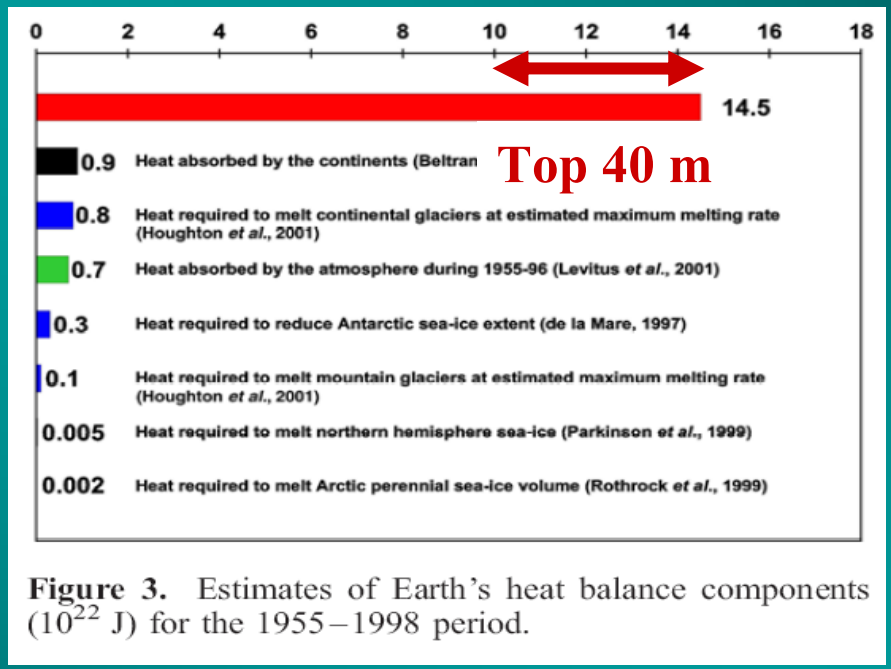
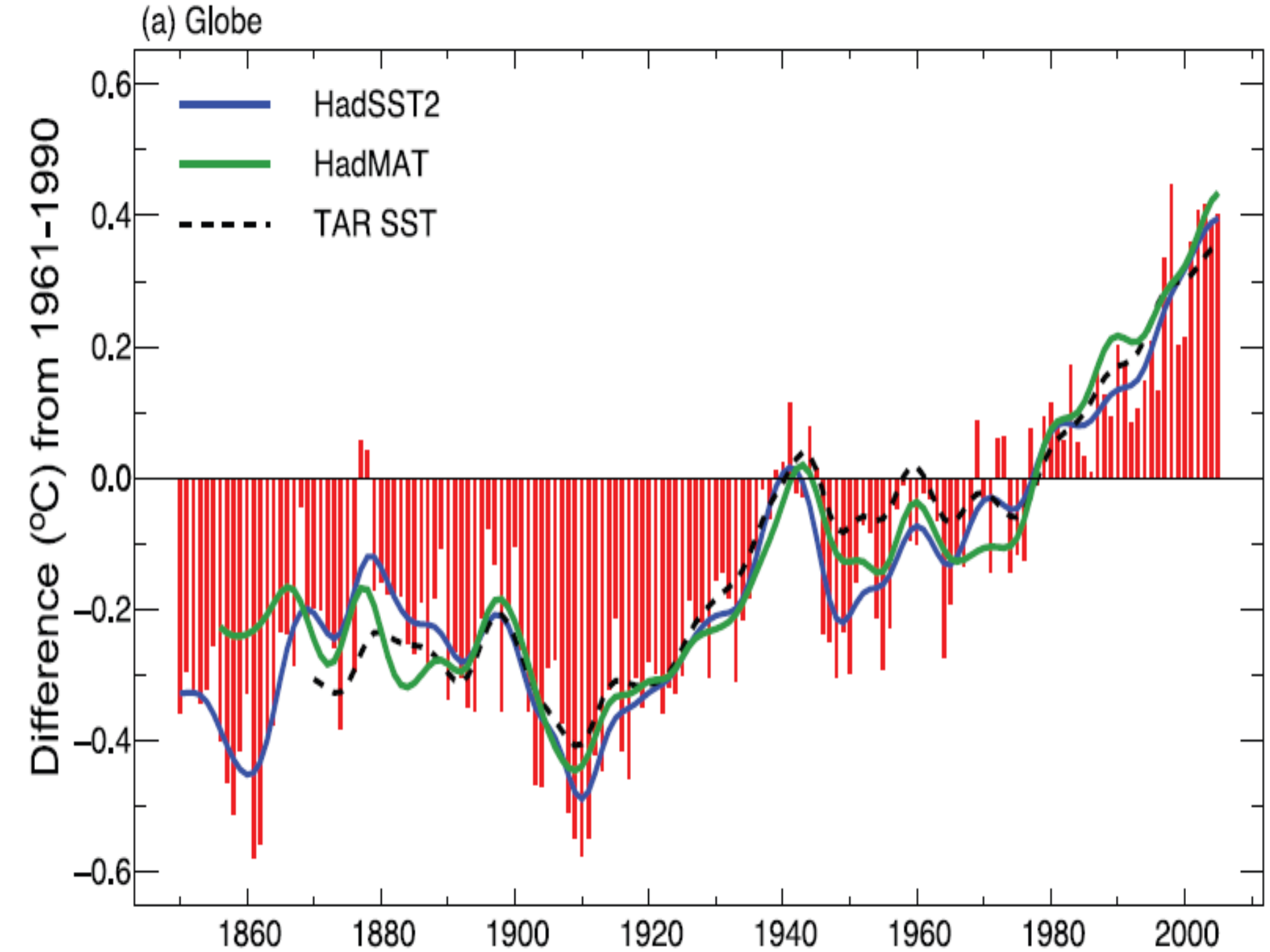


Figure 3. Estimates of Earth's heat balance components (10^{22} J) for the 1955–1998 period.

Fundamental Climate Data Records and Products

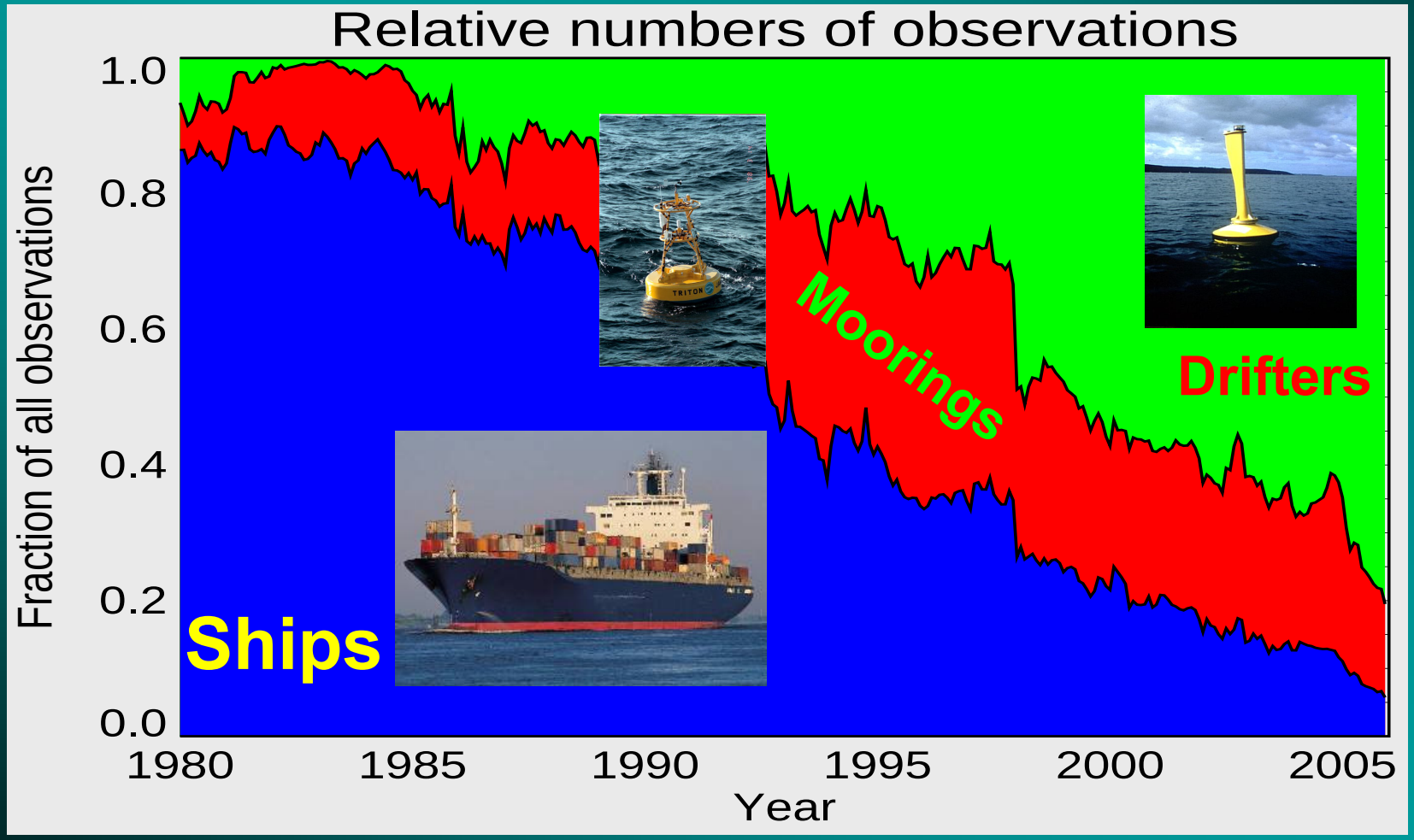
"long term data record ...overlaps and calibrations sufficient to allow homogeneous products ... accurate and stable enough for climate monitoring"

"some products should be based on independent FCDRs"


(a) Globe
HadSST2
HadMAT
TAR SST
Difference (°C) from 1961-1990
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
1860
1880
1900
1920
1940
1960
1980
2000

Maximum impact objective for SST-CDR

Assess ocean temperature changes independently of current marine CDR.



Sea Surface Temperature as an Essential Climate Variable

Standards for SST-CDR

How to get there?

- Advanced techniques.
- Reprocessibility.
- Potential threats.
- A system of sensors: resilience.

Standards for SST-ECV

GlobColour / Medspiration Workshop, 19-20 November 2008, ESRIN, Frascati.

To meet the ECV challenge …

UTILITY TO UNFCCC / CLIMATE SCIENCE

The extent to which accuracy remains constant in time.

Homogeneity

Independence

Error characterisation

} of SSTs

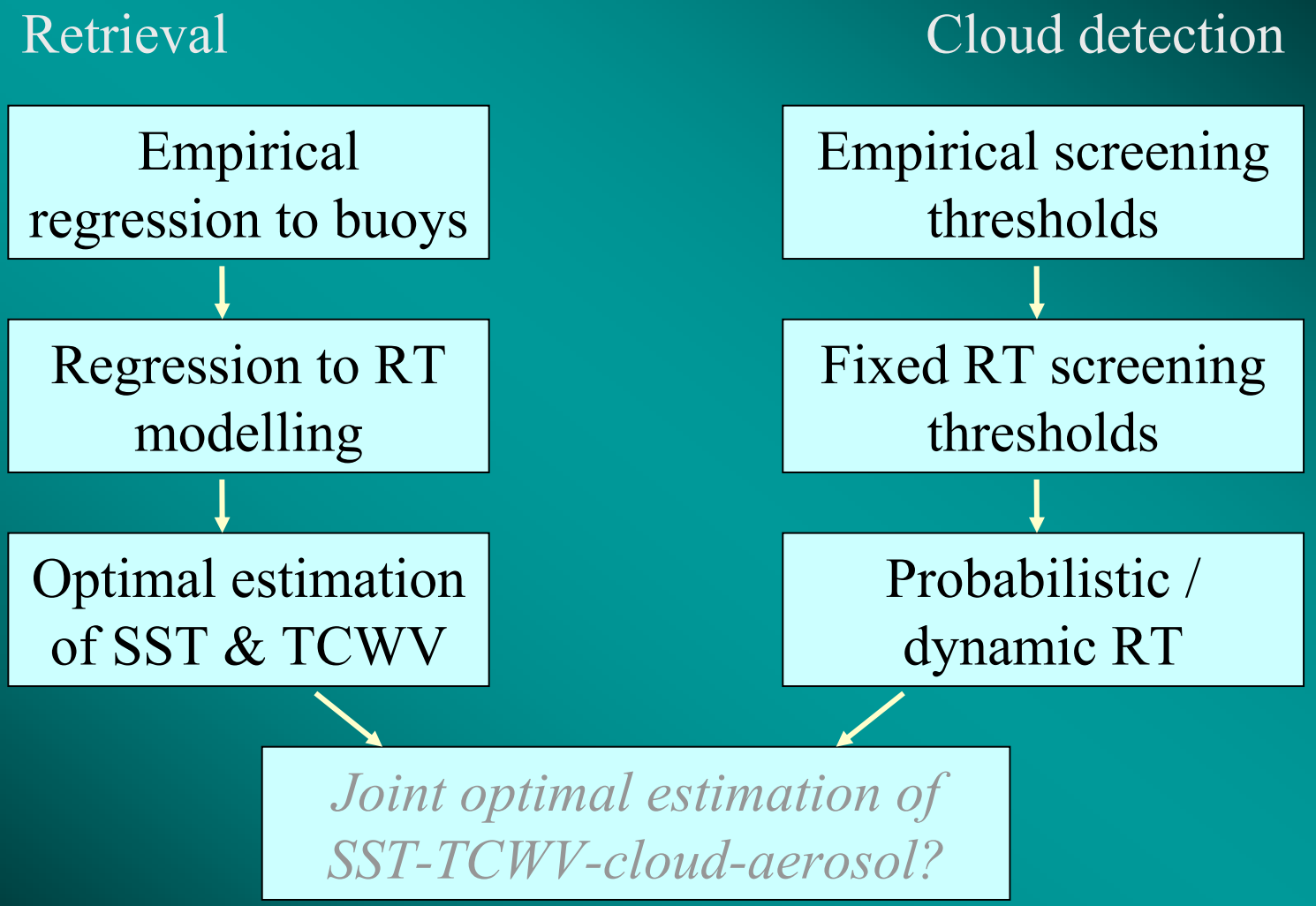
Excellent sensors, characterised, calibrated

Example: (A)RC targets

1. Independent record of ≥15 years of SSTs
2. 5 km radiometric (skin) and foundation (bulk) SSTs
3. Biases <0.1 K, regionally
4. Target stability ≤0.05 K decade^{-1}, regionally
   i. Discontinuities understood & removed
   ii. Consistency between sensors <<0.1 K
5. Comprehensive error characterization:
   i. Retrieval errors (random and systematic, particularly trends)
   ii. Methodological artefacts (channels used, cloud screening)

How to get there?
Advanced techniques

Generations of SST retrieval techniques



Generations of SST retrieval techniques

Retrieval

Empirical regression to buoys

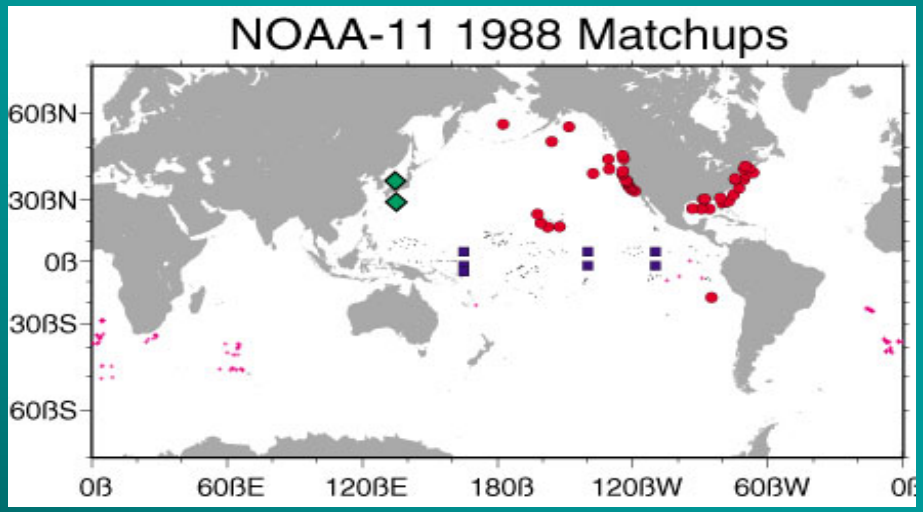
No independence

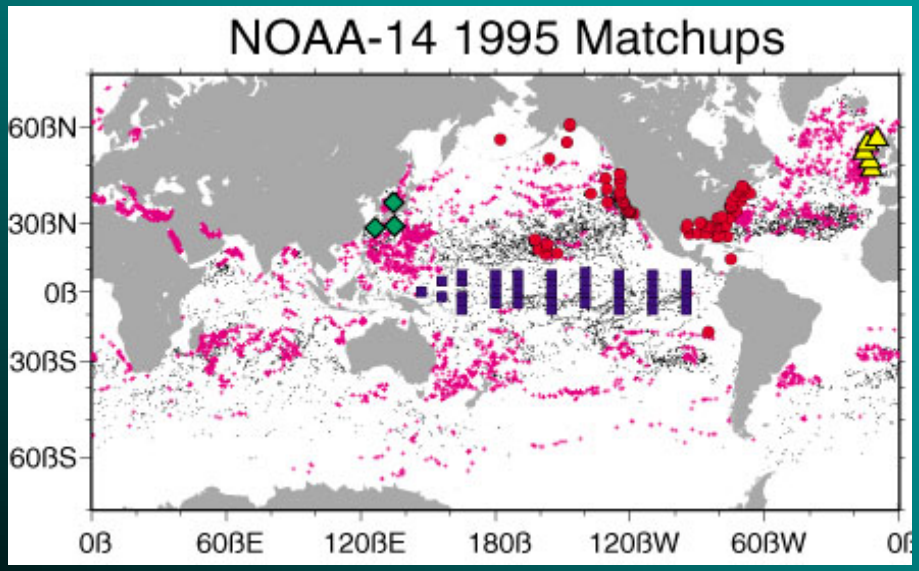
"The objective of the AVHRR Oceans Pathfinder is to develop a long and consistent time series of global sea surface temperature (SST) fields."

http://www.rsmas.miami.edu/groups/rrsl/pathfinder/index.html

>20 year record, widely used

Pathfinder SST tied to *in situ* record





AVHRR SSTs use empirical regression to buoy matches to define retrieval coefficients.

To some degree, this "calibrates" the SST retrieval.

Retrieval is best where matches are and of unassessed quality elsewhere.

Geographical distribution changes have (unassessed) implications for consistency and stability.

No independence from in situ.

Generations of SST retrieval techniques

Retrieval

Empirical regression to buoys

↓

Regression to RT modelling

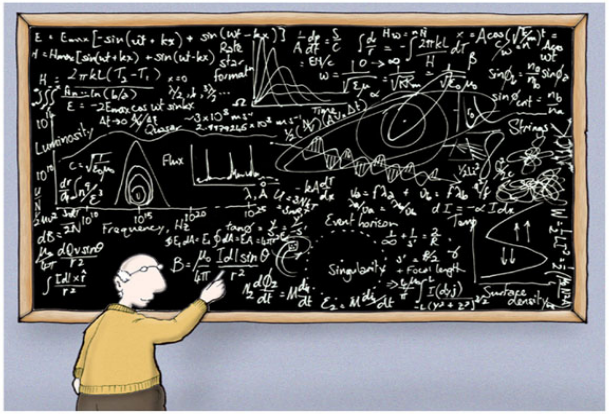
No independence

Apparent independence – but not really

"Second generation" not tied to *in situ* record

Retrieval based on radiative transfer (physics)

Spectroscopy of trace gases, aerosol
Water vapour continuum absorption
Water surface emissivity
Instrumental characterisation



… a lot of hard work

Apparently "independent"

Local (mis)behaviour

Algorithm

$$\hat{x} = a_0 + a_1 S + \left(a_2 + a_3 S\right) y_{11} + \left(a_4 + a_5 S\right) y_{12}$$

Sensitivity to water vapour, w

$$\partial\hat{x} \Big/ \partial w = \left(a_2 + a_3 S\right) \partial y_{11} \Big/ \partial w + \left(a_4 + a_5 S\right) \partial y_{12} \Big/ \partial w$$

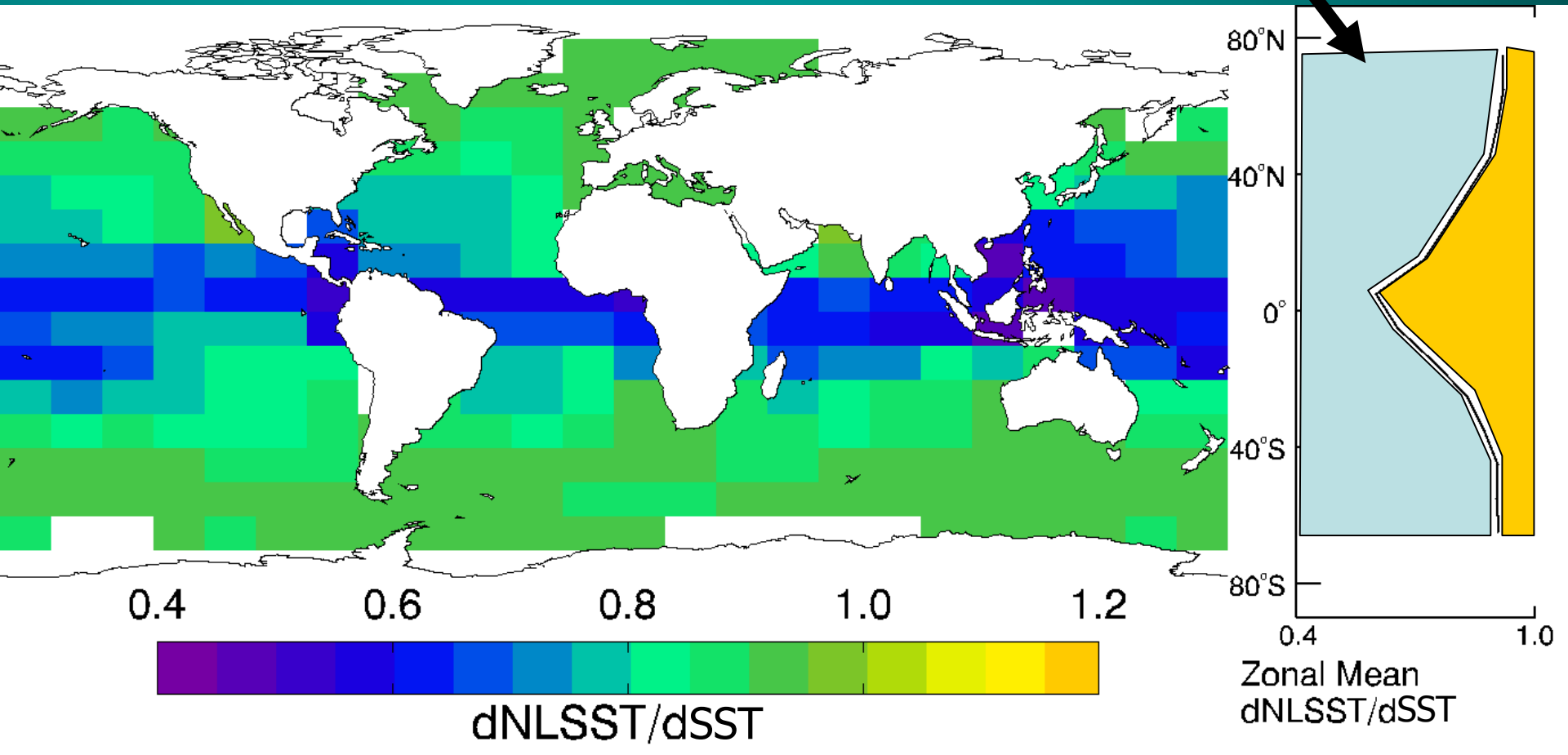
Sensitivity to true SST, x

$$\partial\hat{x} \Big/ \partial x = \left(a_2 + a_3 S\right) \partial y_{11} \Big/ \partial x + \left(a_4 + a_5 S\right) \partial y_{12} \Big/ \partial x$$

But still has hidden dependence

From "prior error" – should not be in an "independent" CDR.

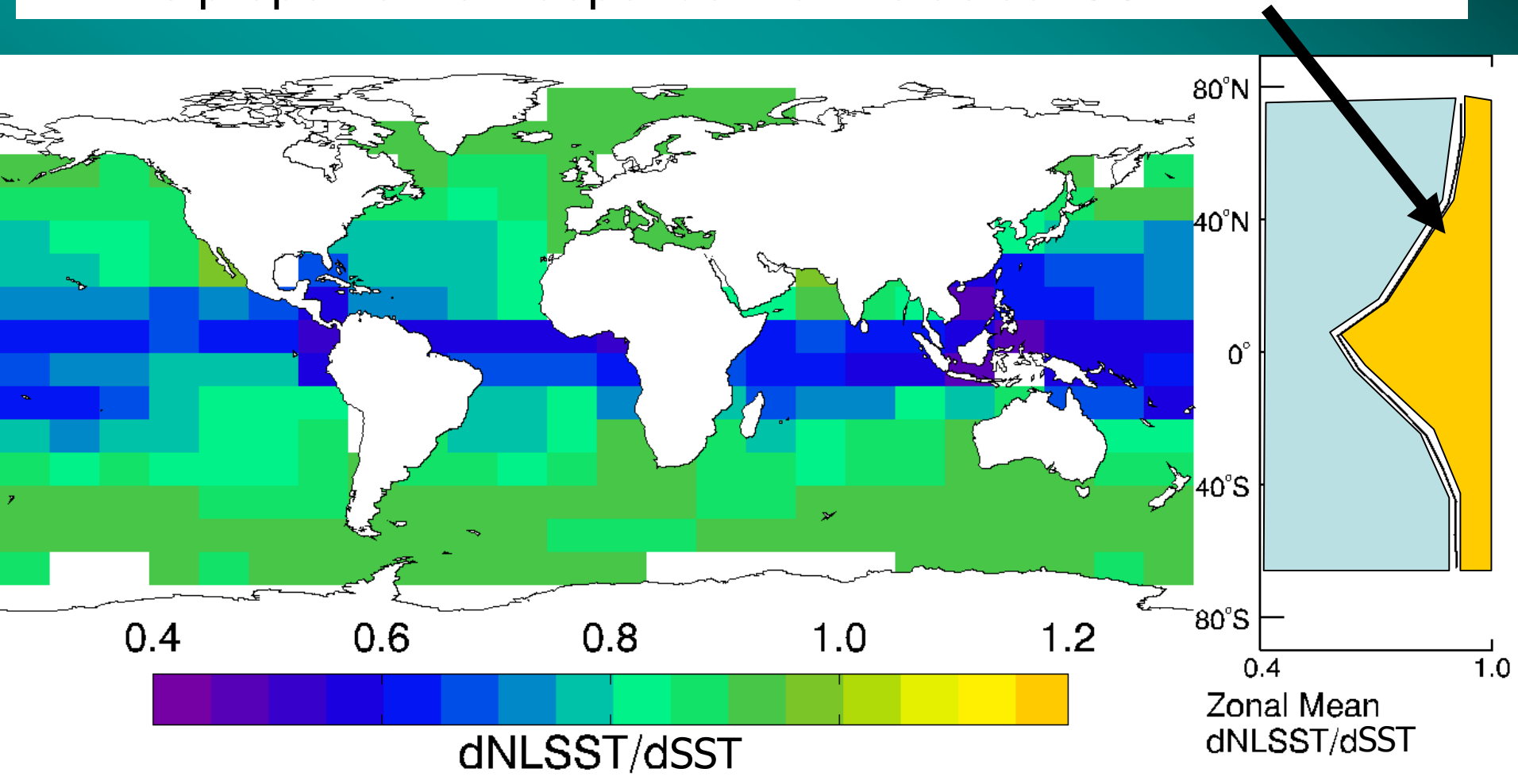
This proportion is information provided by the satellite observations



But still has hidden dependence

From "prior error" – should not be in an "independent" CDR.

This proportion is independent of the actual SST



Generations of SST retrieval techniques

Retrieval

Empirical regression to buoys

↓

Regression to RT modelling

↓

Optimal estimation of SST & TCWV

No independence

Apparent independence – but not really

Can be truly independent* - maximum likelihood

(*but not single view 11/12 um)

Generations of SST retrieval techniques

- First: empirical regression to buoys
  - Operational stalwart from ~1984 to present
  - Pathfinder re-analysis
- Second: regression to physical modelling
  - ATSR, but limited success prior to ~1998
  - Meteo-France and NOAA geo's since ~2000
  - (A)RC & Sentinel-3 ATBD [ongoing]
- Third: joint optimal estimation of SST & WV
  - (A)RC [ongoing]
  - Coming soon: Meteo-France and NOAA geo's
- Fourth: joint OE of SST-WV-cloud-aerosol?

From Medspiration / GHRSST …

OPERATIONALITY

Ugly word

Timely dissemination

Common standards

Reliability

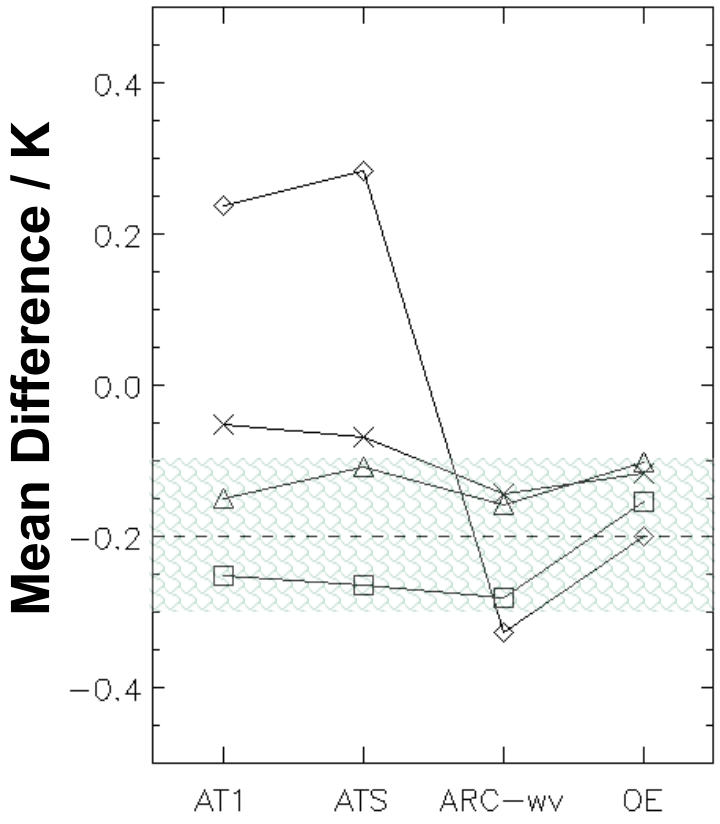
User-driven products

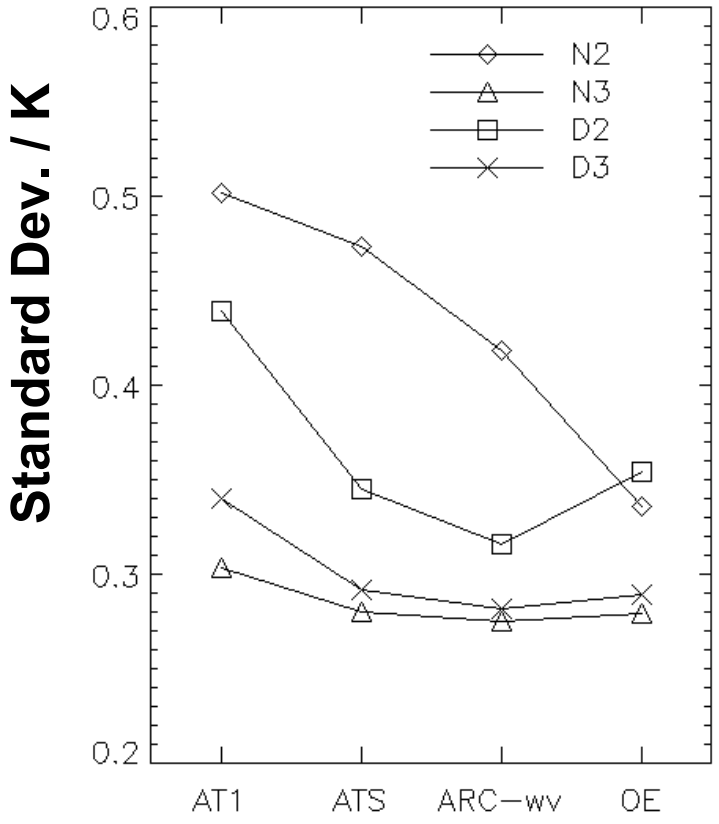
At high spatial resolution

Three (four?) generations of SST retrieval

- First: empirical regression to buoys
  - Not at all independent
- Second: regression to physical modelling
  - Apparently independent – but not really
  - Can have significant dependence on climatology
- Third: joint optimal estimation of SST & WV
  - Can be truly independent
  - (Or can choose to minimize retrieval error)
- Fourth: joint OE of SST-WV-cloud-aerosol?

(A)RC AATSR v. drifters

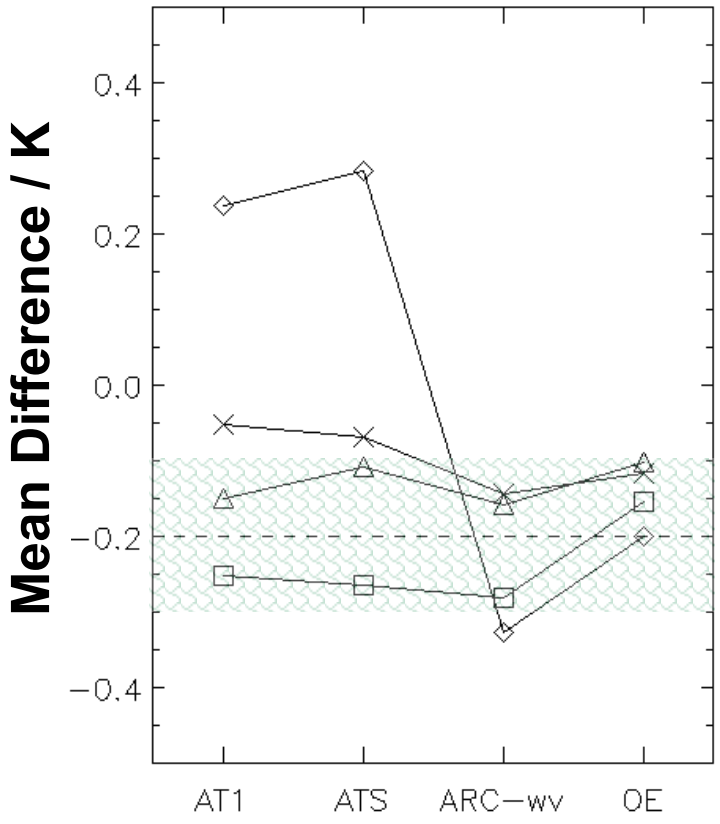


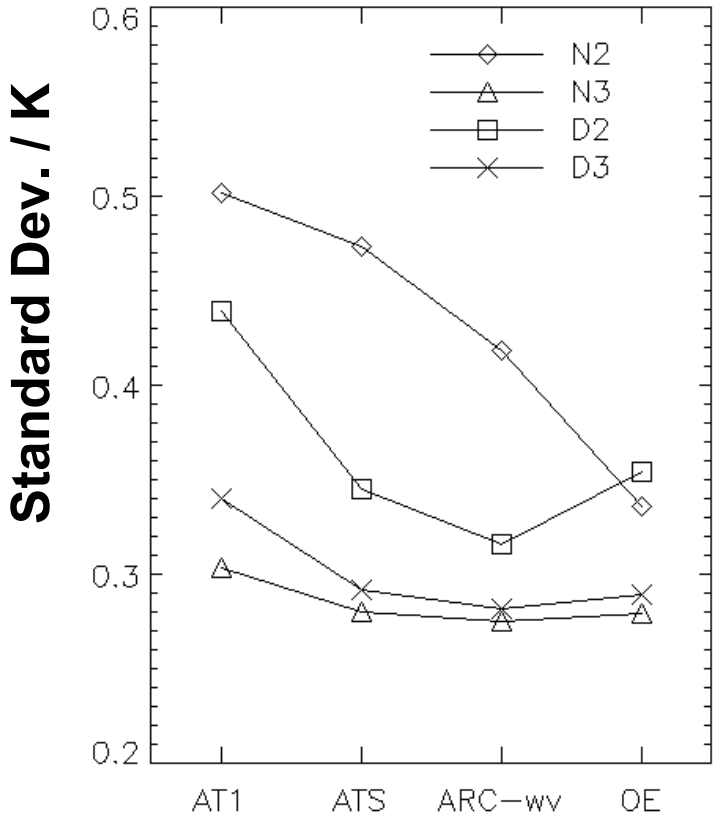


Operational coefficients

+ 12 um correction, forward view offset

(A)RC AATSR v. drifters





Operational coefficients, 12 um correction,
forward view offset **+ Bayesian cloud detection**

Summary for "ARC-wv"

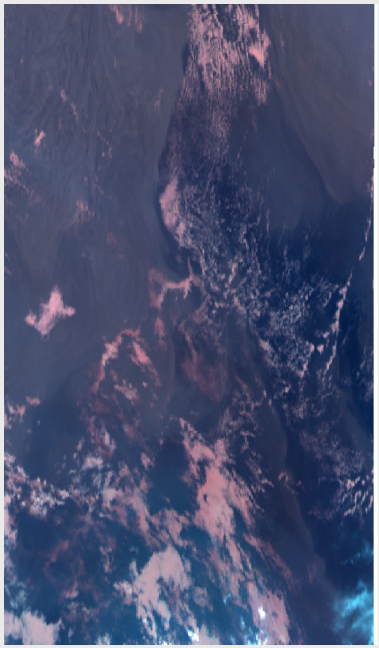
- 5x5 pixels colocated with buoy where:
  - Night-time, more than 1 clear-sky pixel
- ARC linear retrieval with TCWV bands
- Subskin-Skin correction from Donlon et al. 2002

	N2	N3	D2	D3
Bias	-0.060	0.085	-0.045	0.092
Noise	0.397	0.262	0.296	0.271

Bayesian Cloud Detection

http://www.geos.ed.ac.uk/gbcs

Sensor & channels characteristics



Imagery

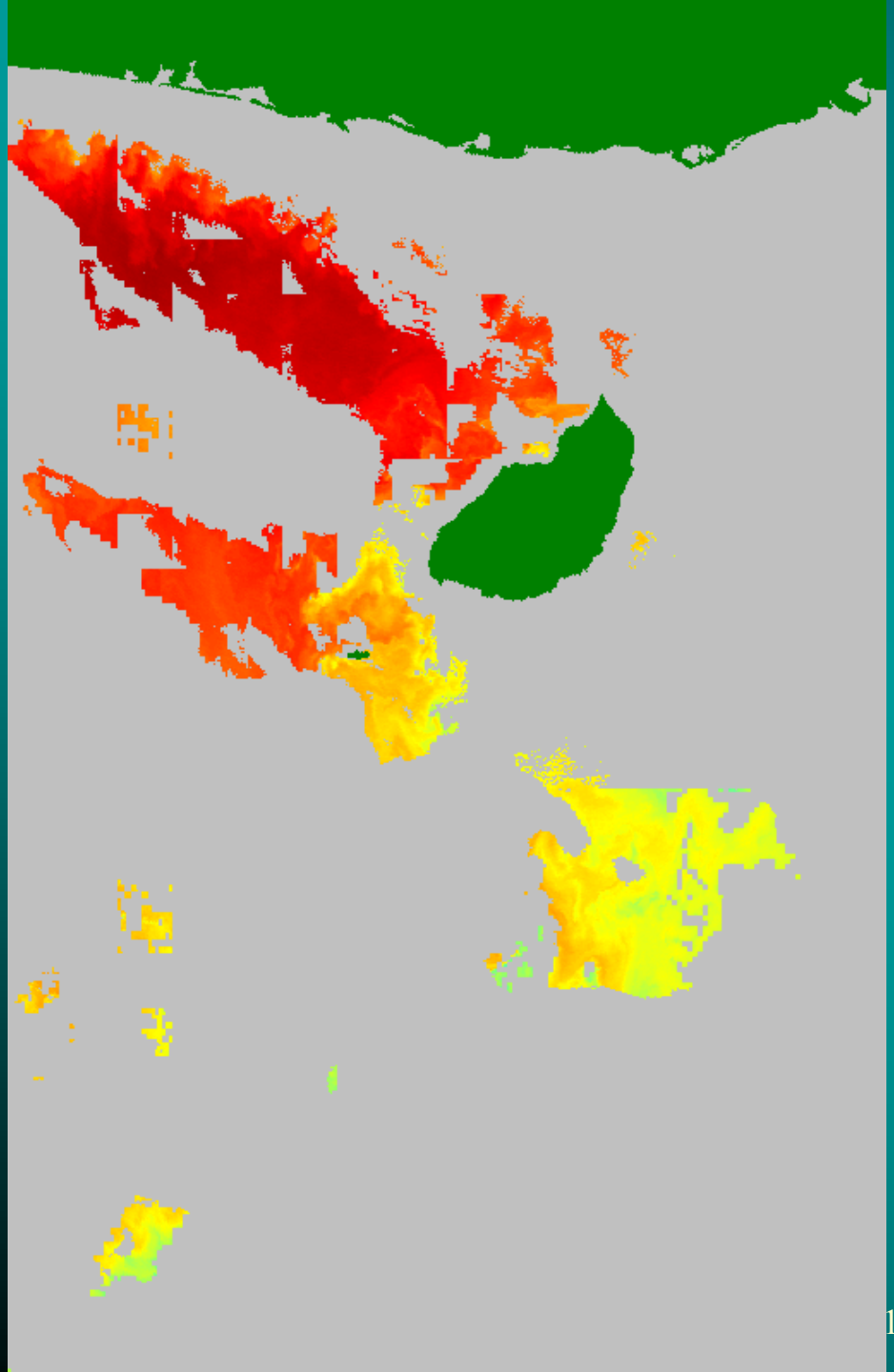
Merchant, Harris et al., *Quat J Royal Met Soc*, 131, 2735ff, 2005

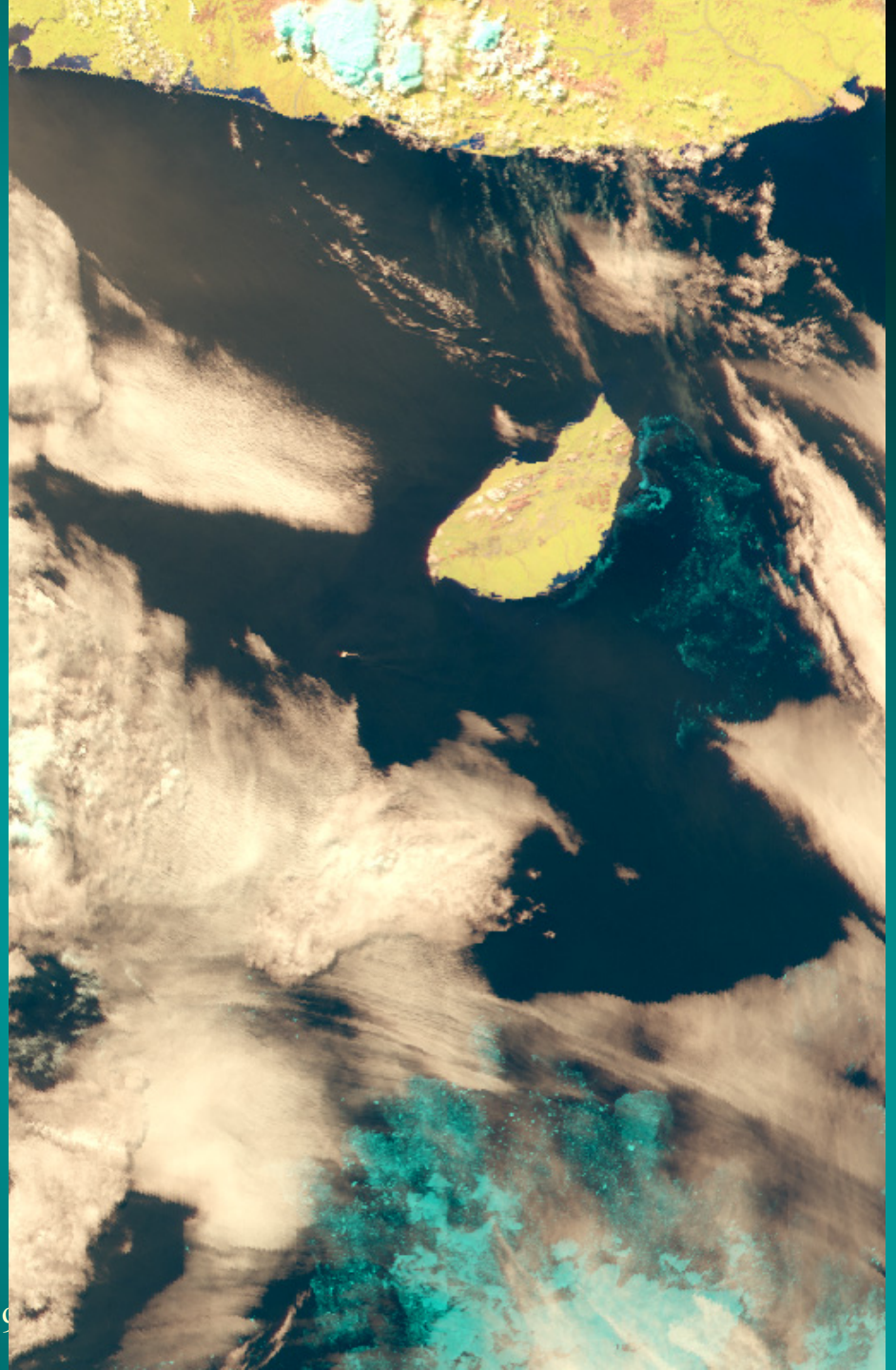
Calculate probability each pixel is clear

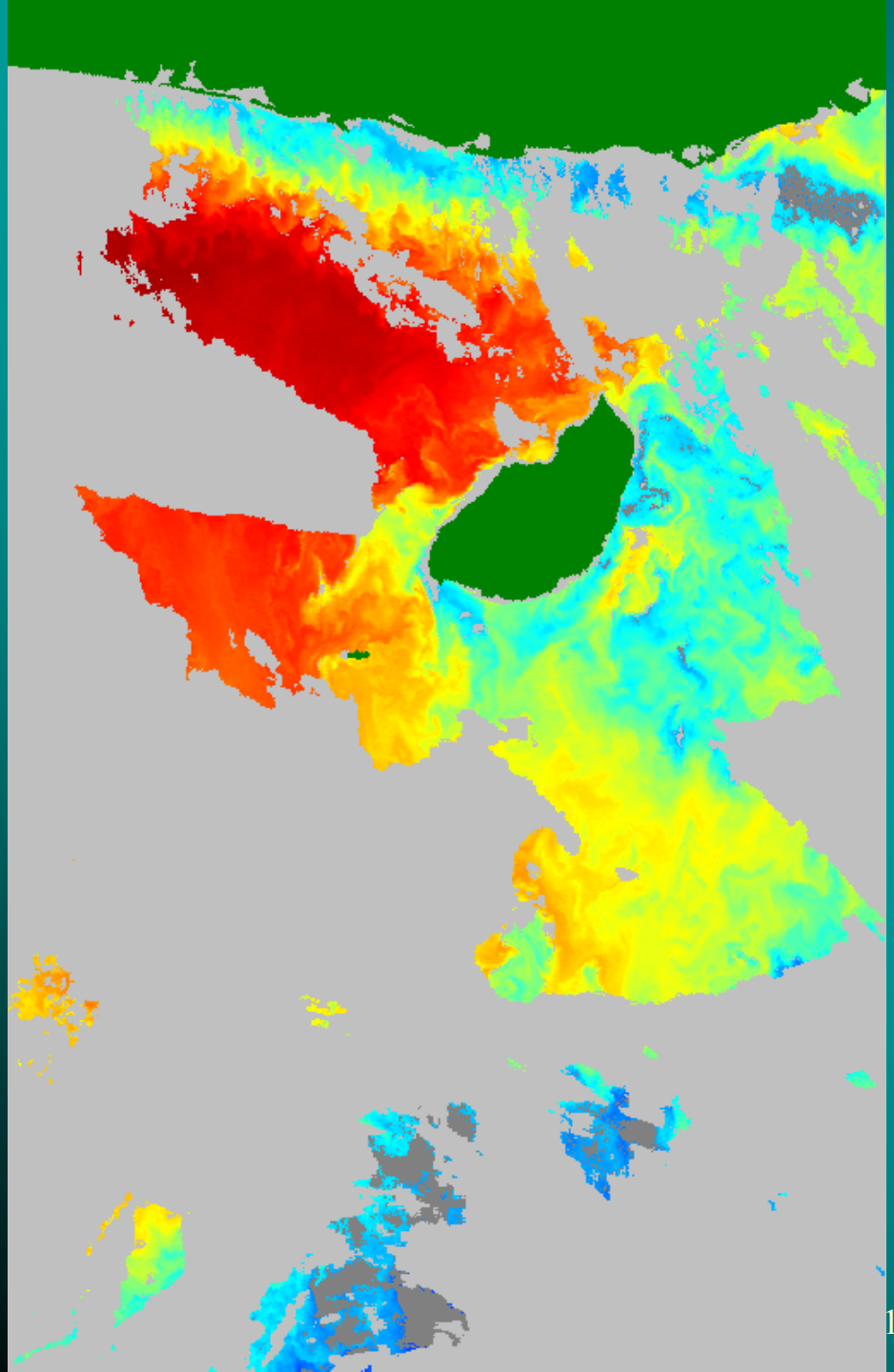
NWP FIELDS + ERRORS
+ FORWARD MODEL FOR SENSOR + NOISE

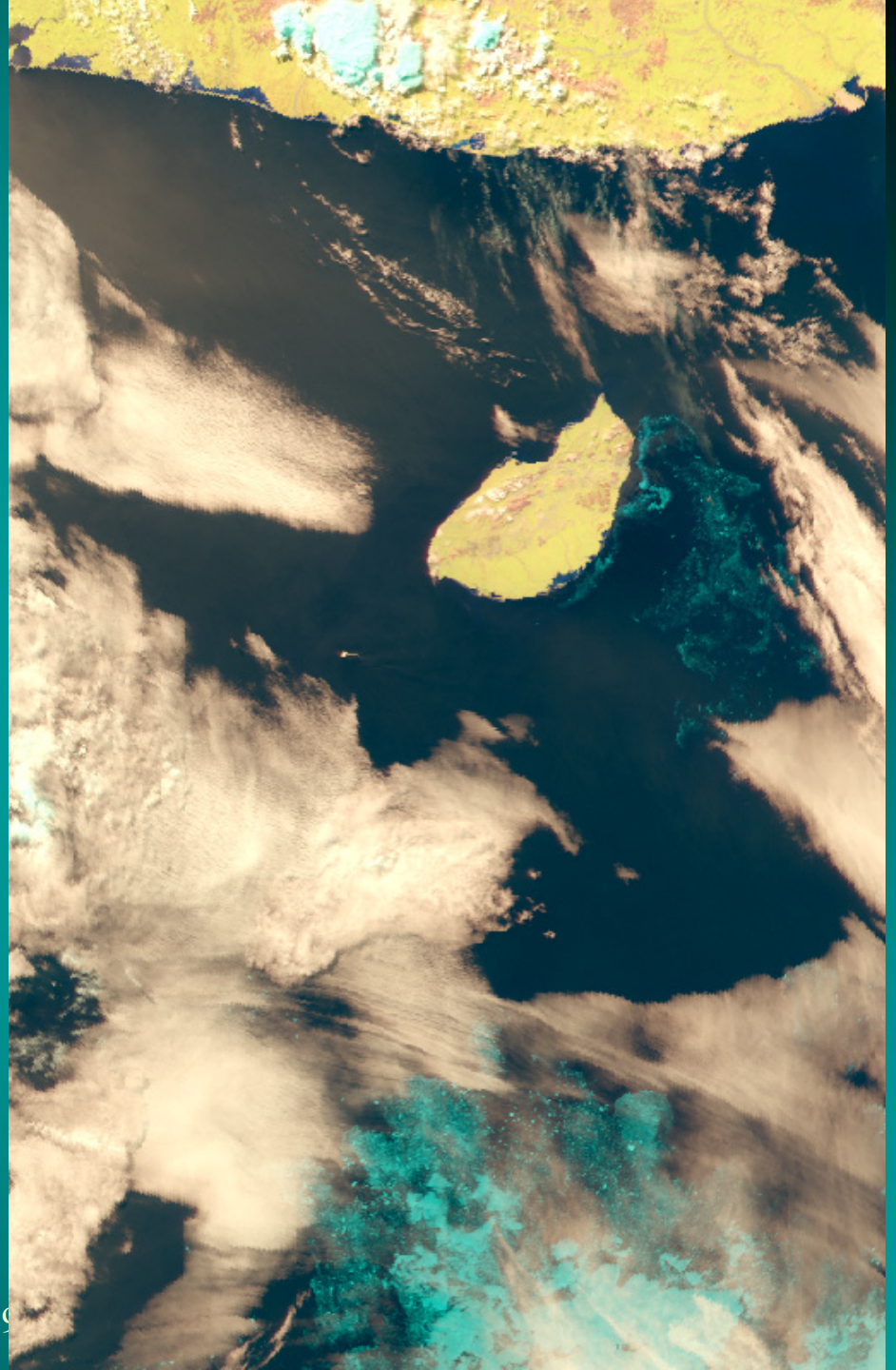
Cloud mask

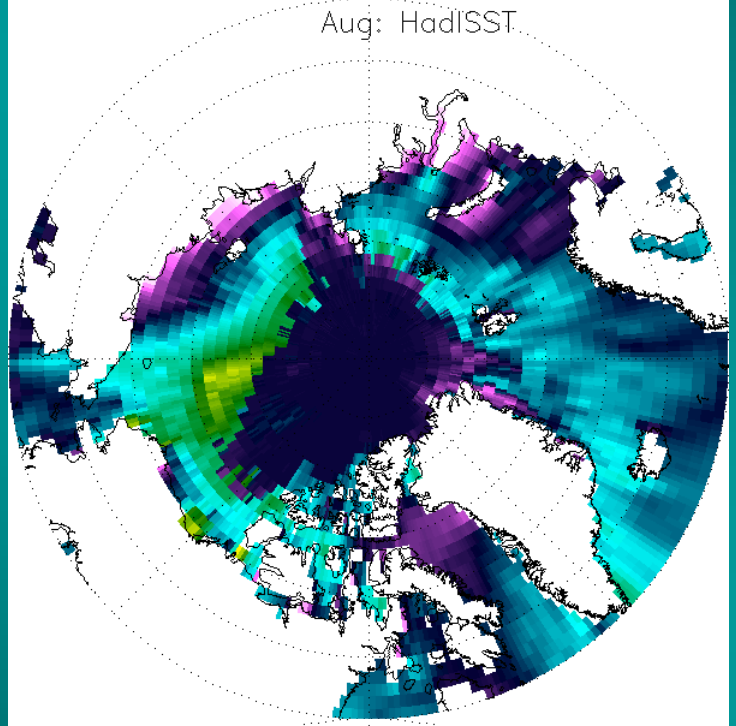
P > threshold

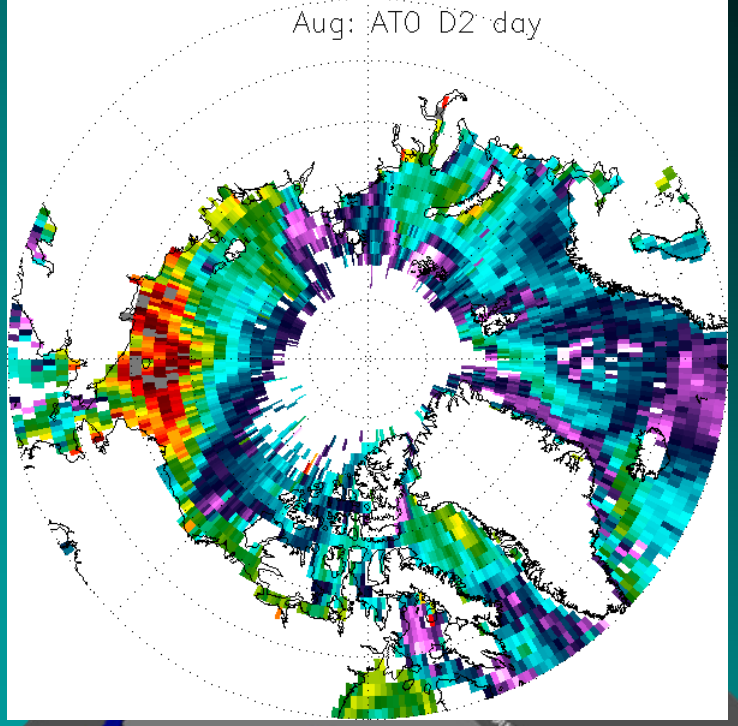


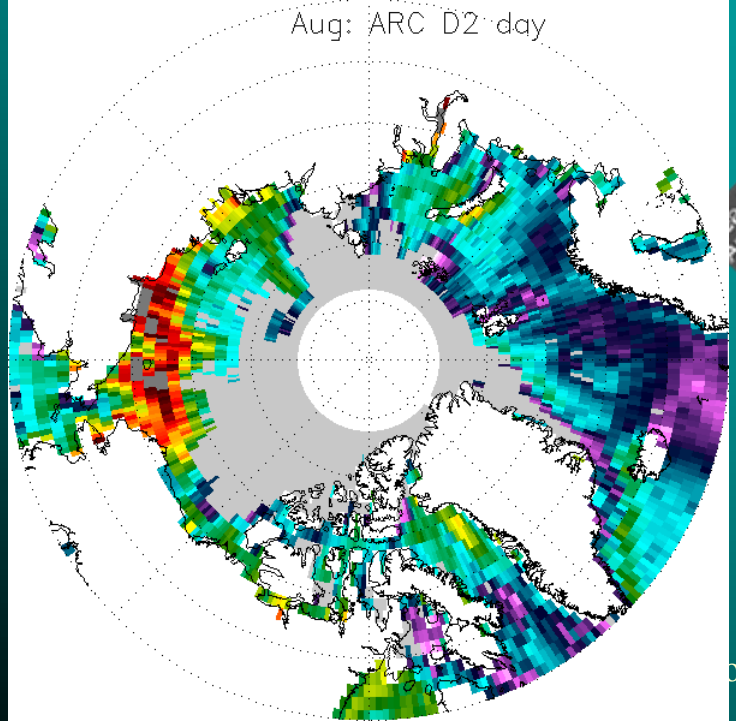


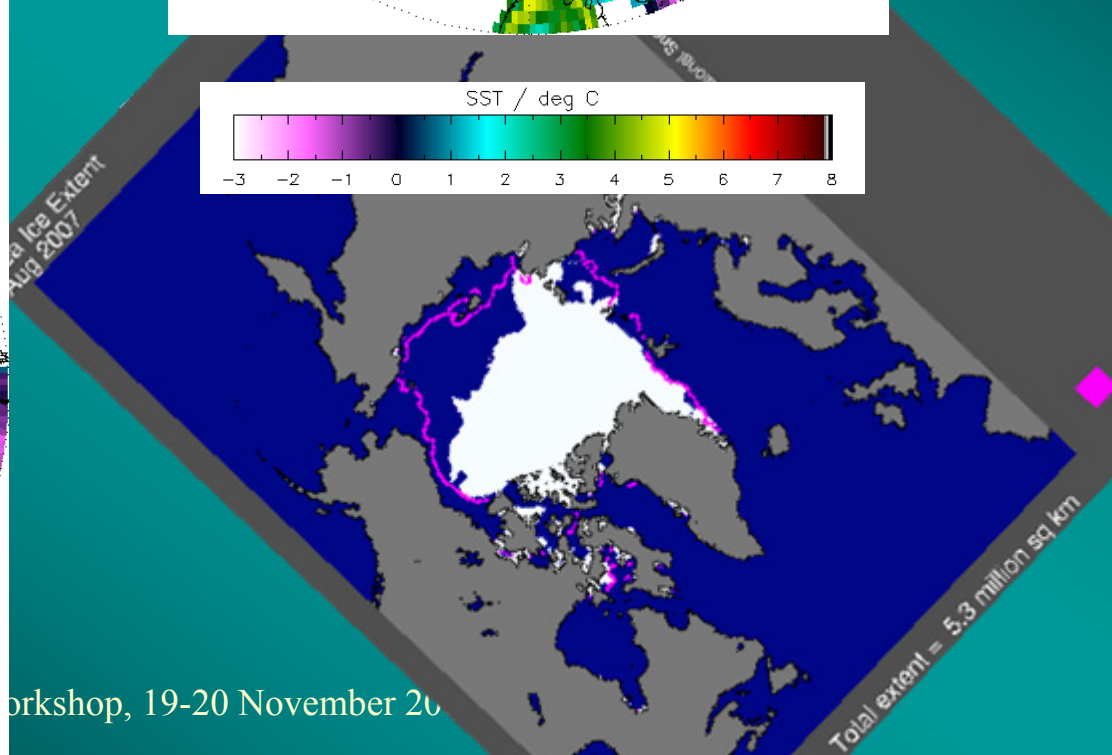




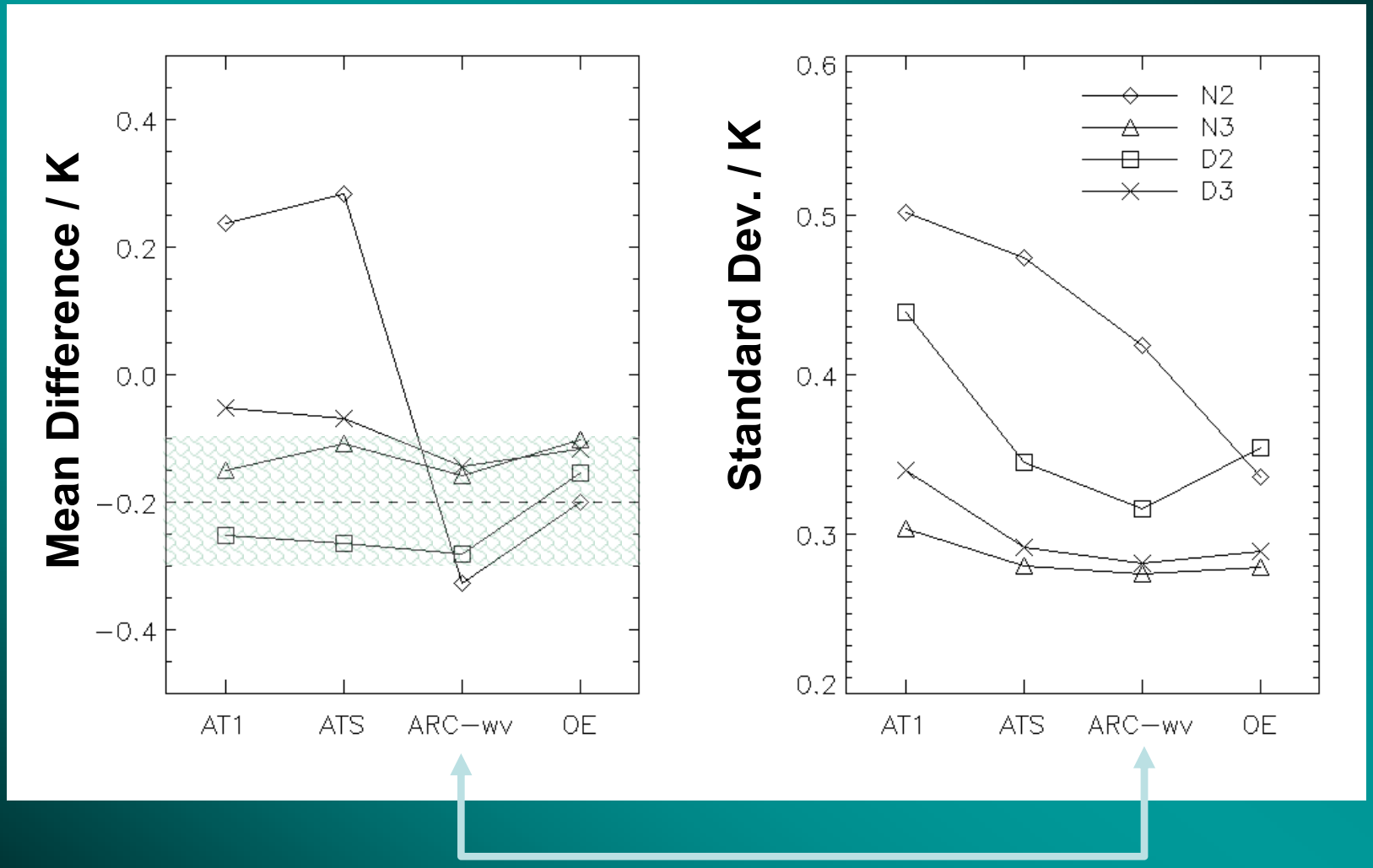

Aug: HadISST


Aug: ATO D2 day


Aug: ARC D2 day

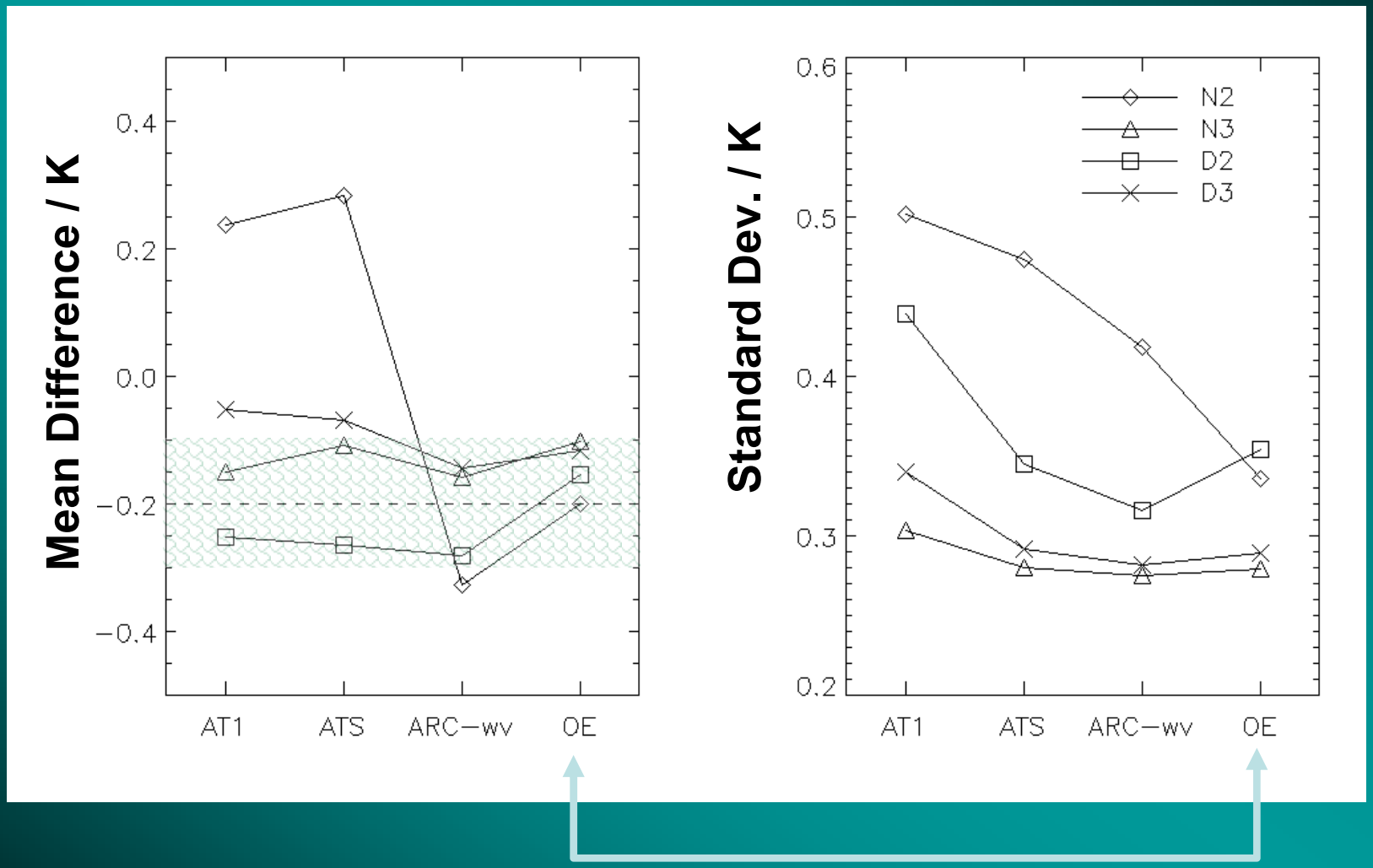

SST / deg C
−3 −2 −1 0 1 2 3 4 5 6 7 8
Total extent = 5.3 million sq km

(A)RC AATSR v. drifters



New coefficients, 12 um correction,
forward view offset, Bayesian cloud detection

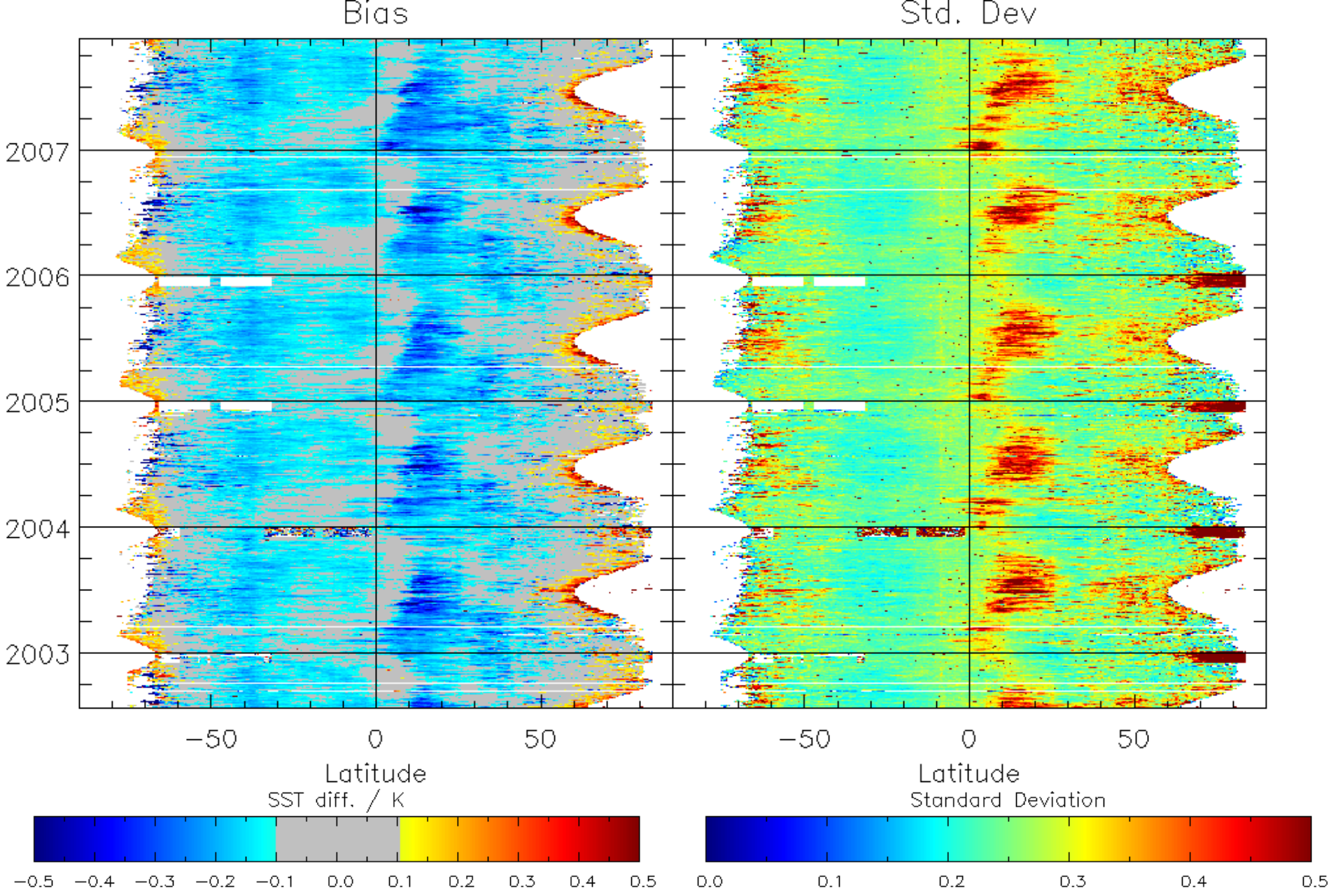
(A)RC AATSR v. drifters



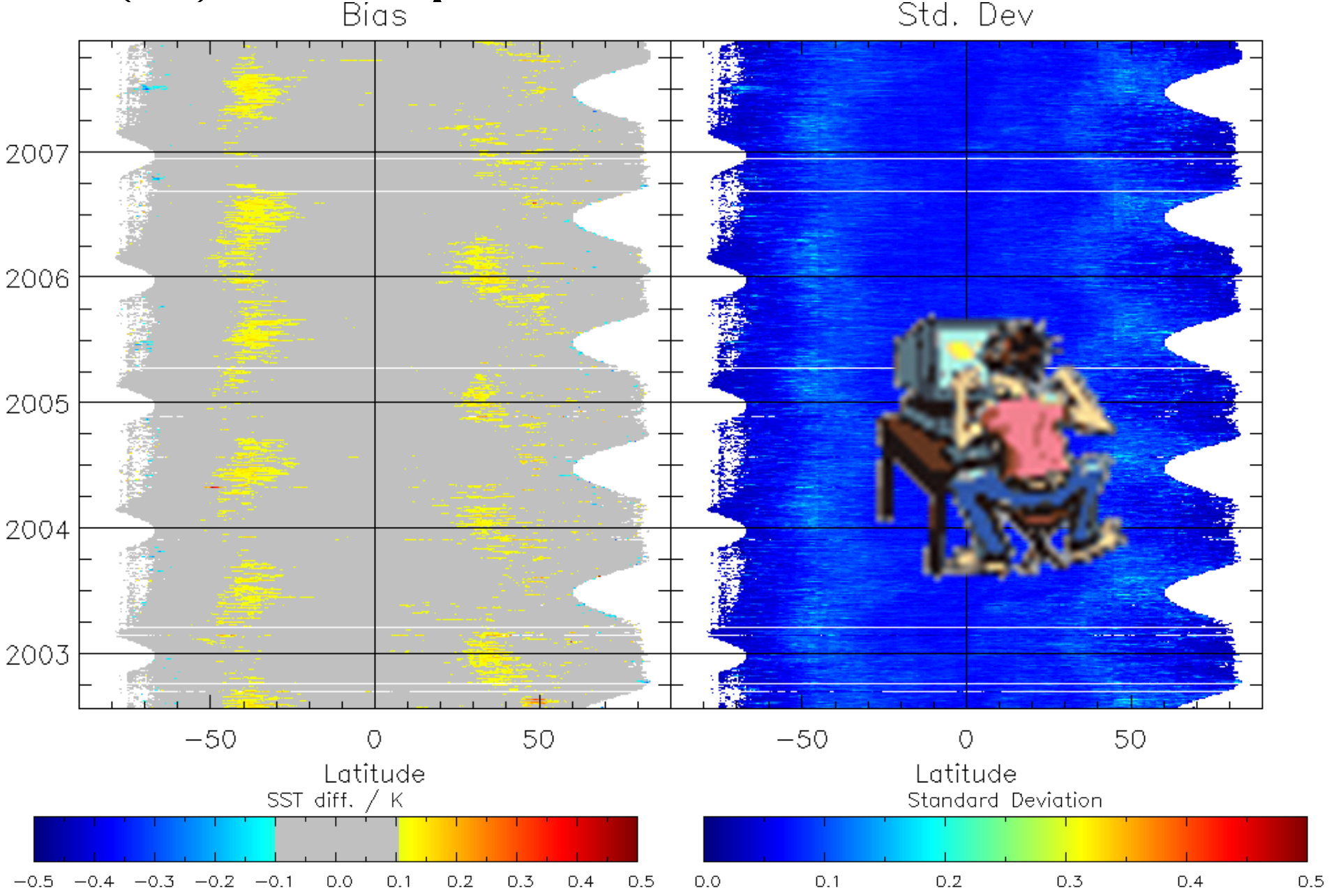
Optimal estimation (aka physical retrieval, MAP)

12 um correction, forward view offset, Bayesian cloud detection

AATSR Operational: N3 – D3



(A)RC experimental OE: N3 – D3

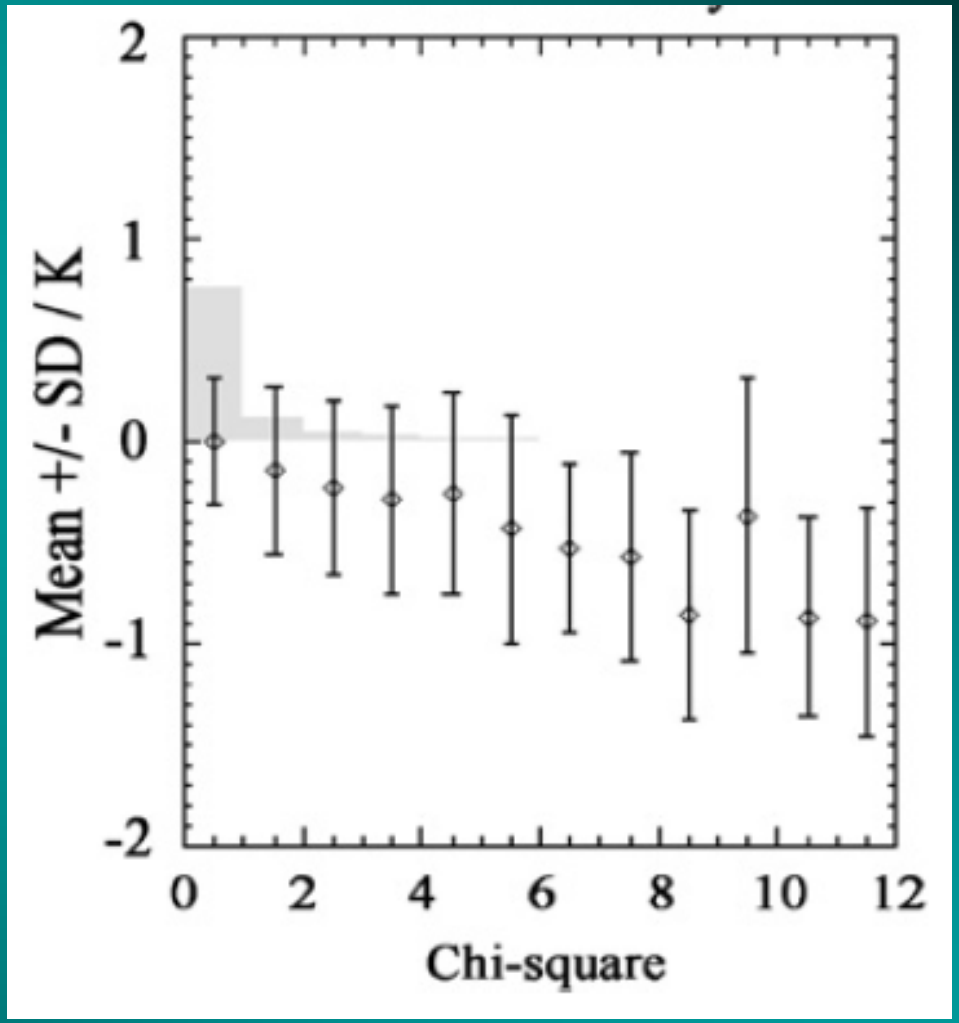


OE and error characteristics

Example of Metop SST by OE

Chi-square metric emerges from OE and is powerful quality indicator

Best 75% of data has 0.0 K bias and SD 0.25 K



How to get there?
Reprocessibility

Reprocessibility

- SST as ECV requires

  homogeneity and **stability** across missions
- New instruments & chains

  always spring surprises
- Radiative transfer, cloud detection and retrieval techniques

  continue to **improve**

Reprocessibility

IMPLIES

Reprocessing will be needed

Build in “reprocessibility” from the beginning

Example: (A)ATSR / SLSTR

- SLSTR-format archive at S3 launch of ATSR/ATSR-2/AATSR
- Populated in NRT for SLSTR and AATSR during *joint* cal-val phase
- Homogeneity analysis: significant supported activity built-in to cal-val phase
- Auxiliary data to support third-generation techniques embedded in L1b
- GPoD-like capability including RT models

A challenge

Time from ATSR launch to (A)RC SST record:
18 YEARS

For Sentinel-3, <18 MONTHS?

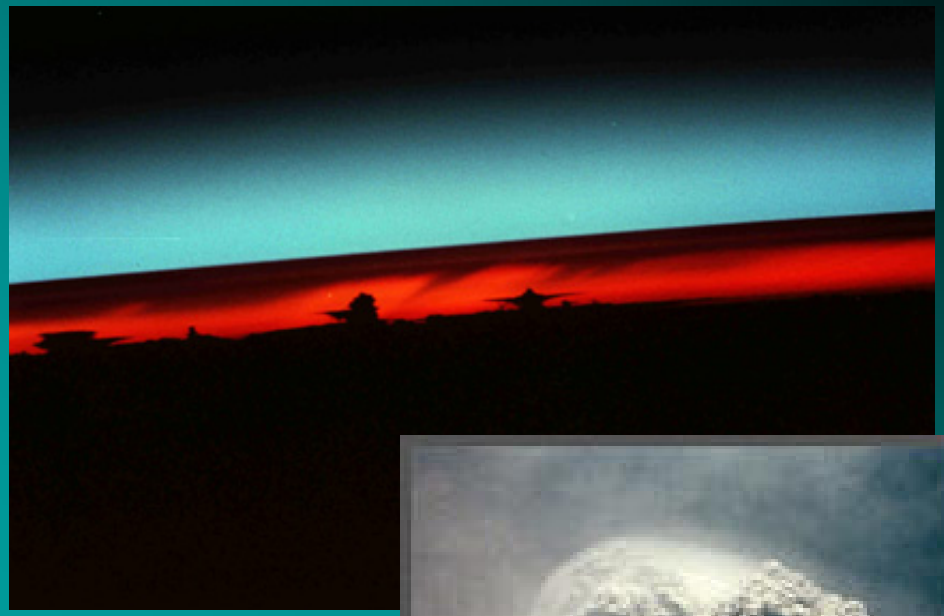
How to get there?
Threats to success

No overlap?

- Envisat mission extension to end 2013
- Sentinel 3 launch end 2012

- Give up on independence for gap period?
  - Use drifter network as transfer standard

- Tie to one or more other sensors
  - E.g., METOP as transfer
  - Reprocessibility – METOP in the (A)ATSR/SLSTR archive?
  - Study this now



Could be very unlucky …

Stratospheric aerosol

+ no dual view IR

+ no passive MW

How to get there?
System of sensors, resilience

A system of sensors

- Only (A)ATSR is capable for SST CDR in their own right
- We have many SST sensors in space
- AATSR SSTs used as reference SSTs
- Could do much better in coming decade

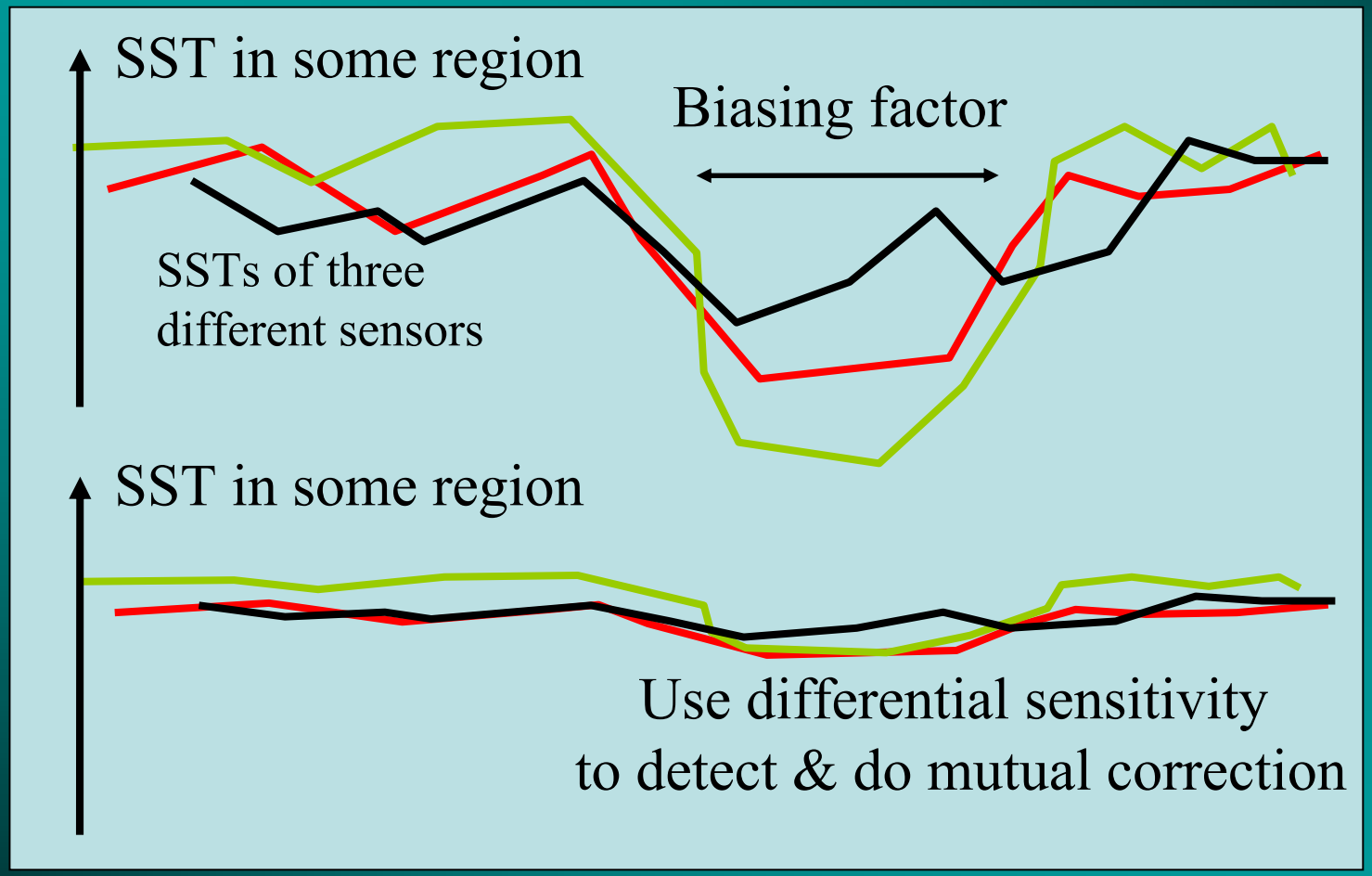
(A)ATSR/SLSTRs as reference sensors

- Bring observing system towards ECV-CDR quality

- Inter-characterisation of SSTs
- Inter-characterisation of BTs/retrieval

- Mutual correction evolving in time, regional
  - Physics of calibration
  - Physics of retrievals and their biases
  - Multi-sensor match-up databases
  - Consolidated SST/BT

Mutual correction



Resilience

- Ideally, go beyond privileging a reference sensor
- Treat all on basis of their error characterisation
- System is resilient to any one sensor being absent
- Need to learn how to do this
  - In principle
  - In operational practice
- Act now while a “reference” sensor is available!

SST as ECV in coming decade

What could be achieved for SST ECV	How to do it
CDR from SLSTRs, <18 mnths + ongoing	
Timeliness	Built-in reprocessibility
Homogeneity with (A)ATSRs	Homogeneity in (joint) cal-val
Independence, error-characterisation	Third-generation techniques
Ongoing SST CDR provision	New techniques into operations
(Benefit to operations)	
Exploit system of sensors for SST CDR	
Bridge Envisat-S3 gap	Reprocessibility with 3rd party
(A)ATSR / SLSTR as reference	Inter-characterisation of BT/SST
Resilience to absence of reference	
Broaden community capability	Processing at archive