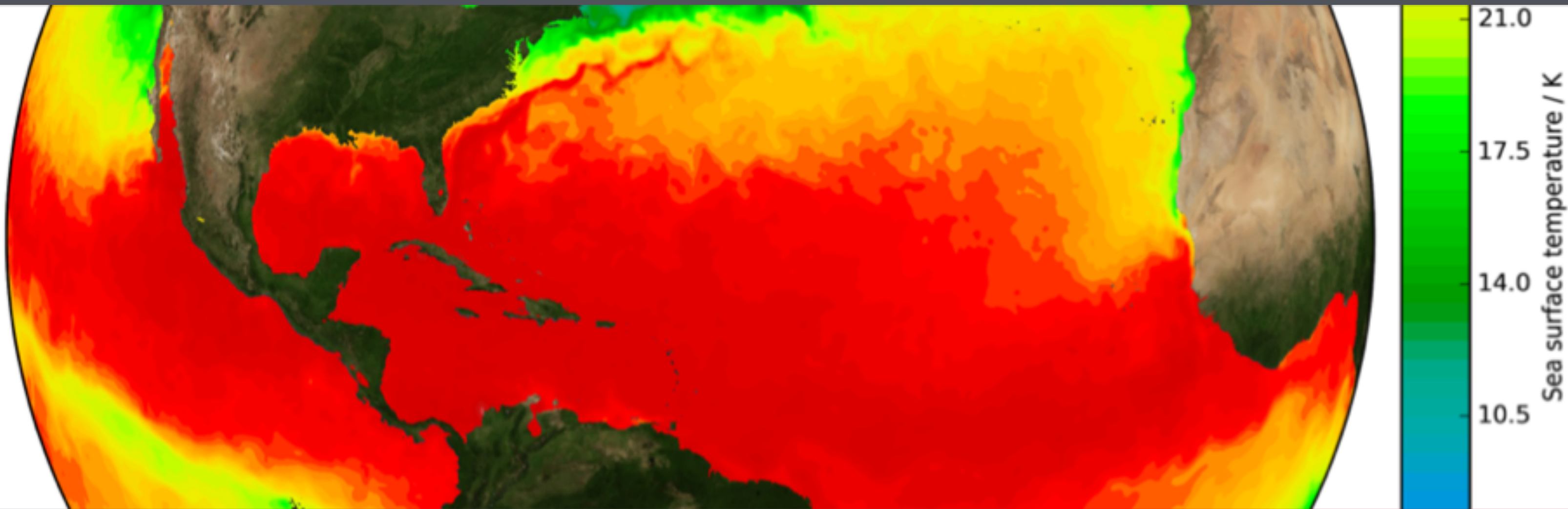
QUANTIFYING THE THERMODYNAMIC STATE OF THE GLOBAL OCEAN SURFACE



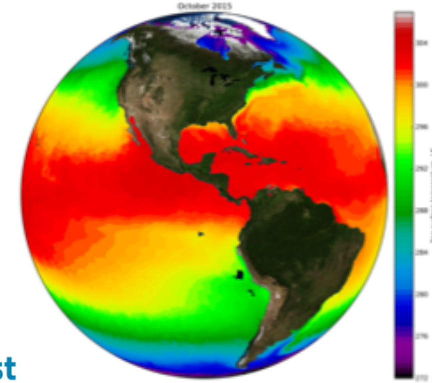
Christopher Merchant

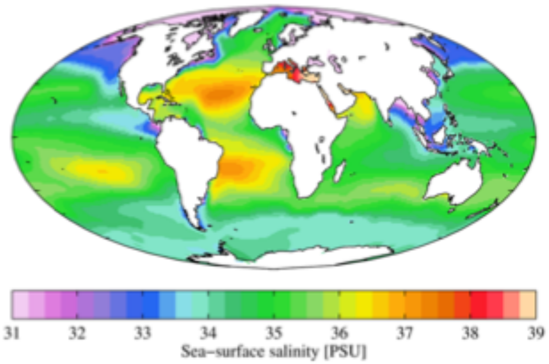
National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

Earth Observation and Space
Department of Meteorology
University of Reading

”Thermodynamic” state : temperature, salinity and “phase”

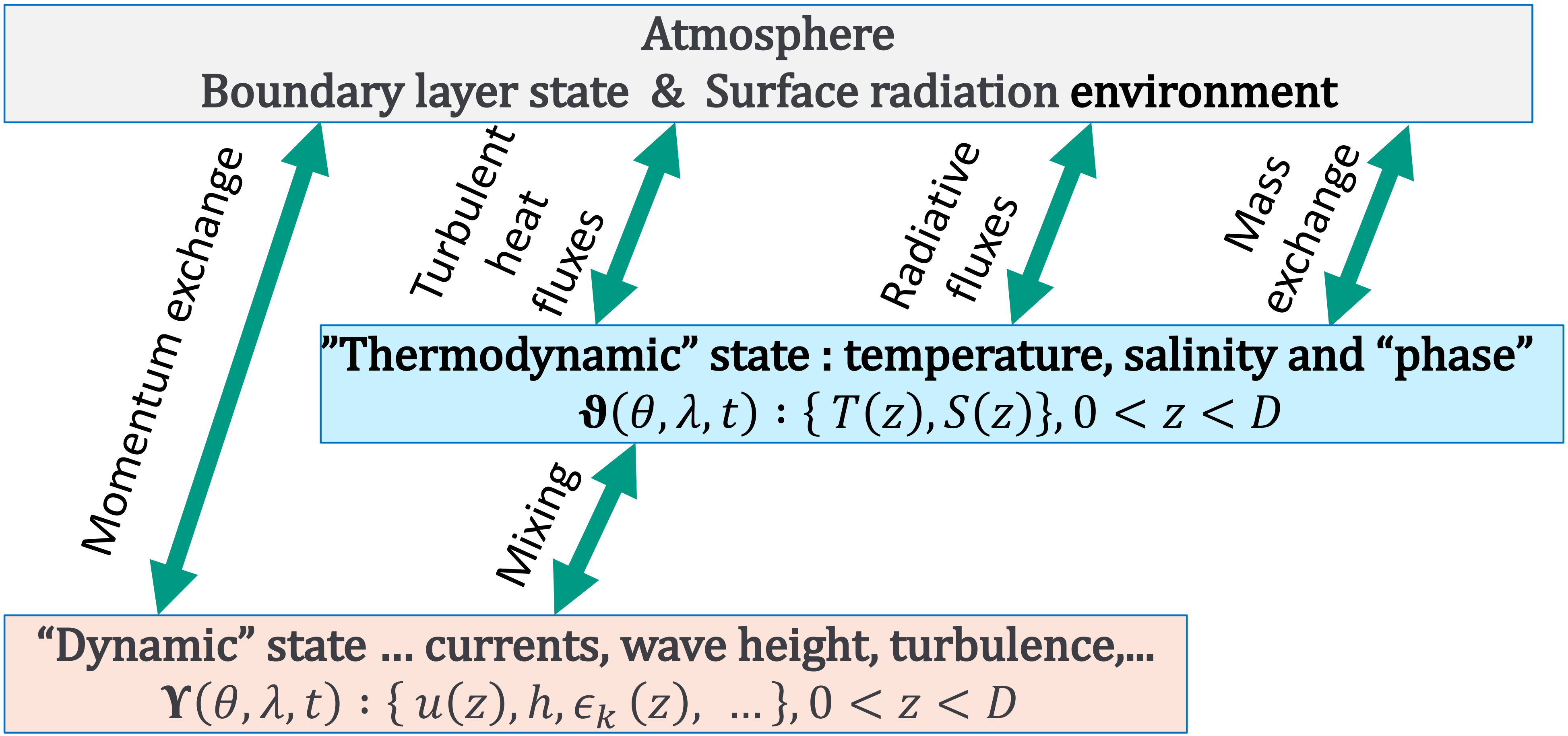
$$\boldsymbol{\vartheta}(\theta, \lambda, t) : \{\, T(z), S(z)\}, 0 < z < D$$





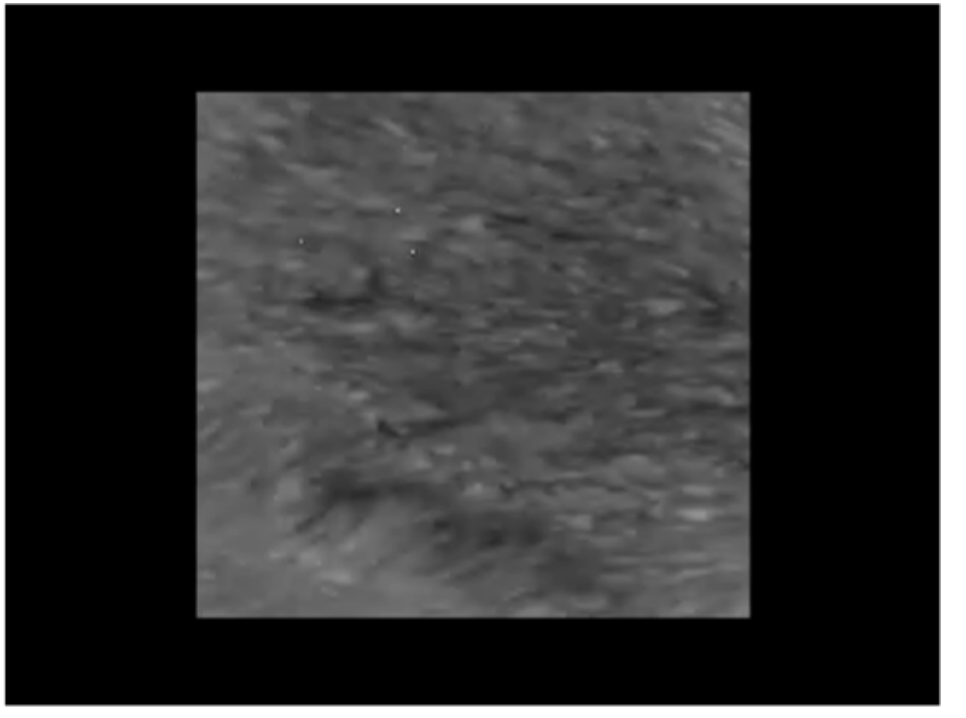
By “Plumbago” from World Ocean Atlas 09

Brash Ice


Atmosphere
Boundary layer state & Surface radiation environment
Momentum exchange
Turbulent heat fluxes
Radiative fluxes
Mass exchange
"Thermodynamic" state : temperature, salinity and "phase"
$\boldsymbol{\vartheta}(\theta, \lambda, t) : \{ T(z), S(z)\}, 0 < z < D$
Mixing
"Dynamic" state ... currents, wave height, turbulence,...
$\boldsymbol{\Upsilon}(\theta, \lambda, t) : \{ u(z), h, \epsilon_k(z), \ ...\}, 0 < z < D$

OBSERVATIONS

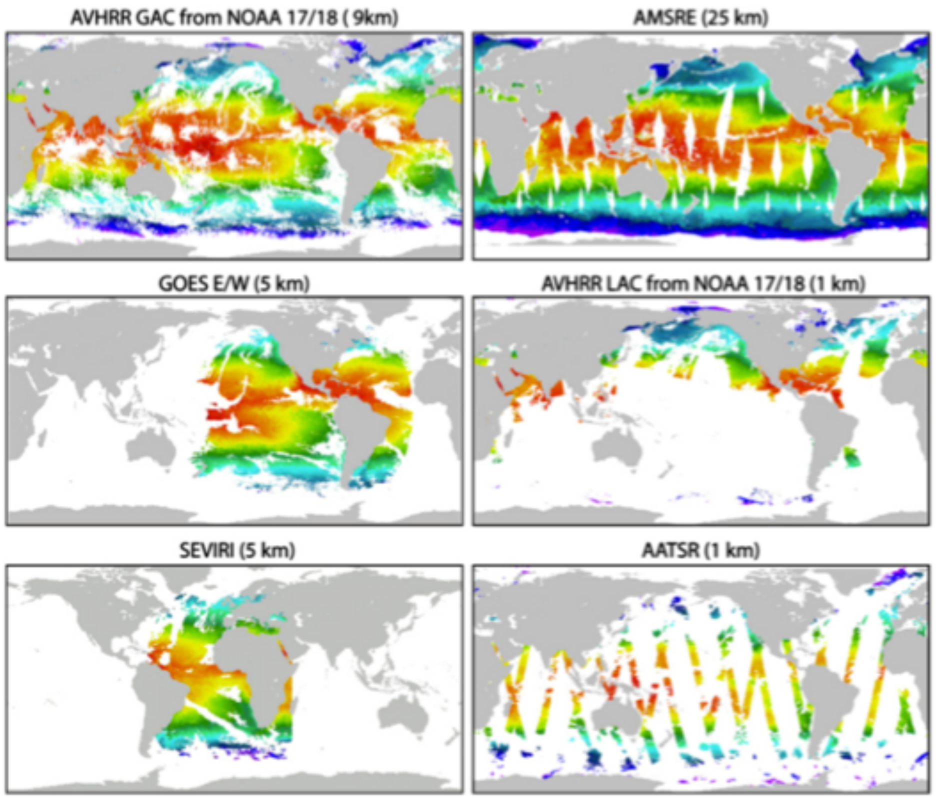
Measurand	Observed by (mainly)	Variability, $\tau \geq ?$
Skin SST	IR satellite	seconds (small scale)



Thermal video by Christopher Zappa, LDEO. Dark = cool. Cool rain disrupts cool skin layer and increases the radiometric skin SST.

OBSERVATIONS

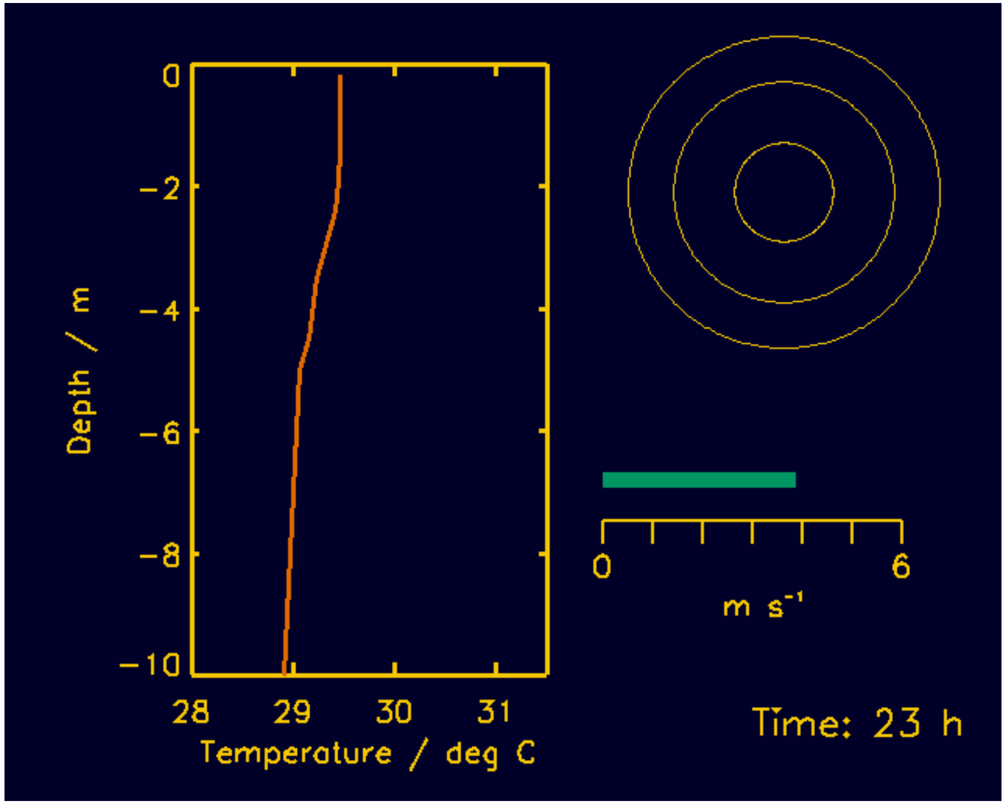
Measurand	Observed by (mainly)	Variability, $\tau \geq ?$
Skin SST	IR satellite	<< hour
Skin Ice ST	IR satellite	< hour
Subskin SST	MW satellite	< hour
$\partial T_{skin}/\partial t$	Geo IR	< hour



Daily IR, MW and Geo IR geographical coverage of SST
From I Robinson 'Measuring the Oceans from Space' 2004

OBSERVATIONS

Measurand	Observed by (mainly)	Variability, $\tau \geq ?$
Skin SST	IR satellite	<< hour
Skin Ice ST	IR satellite	< hour
Subskin SST	MW satellite	< hour
$\partial T_{skin}/\partial t$	Geo IR	<< hour
Depth SST	Buoy	hour
Found. SST	Argo	>days

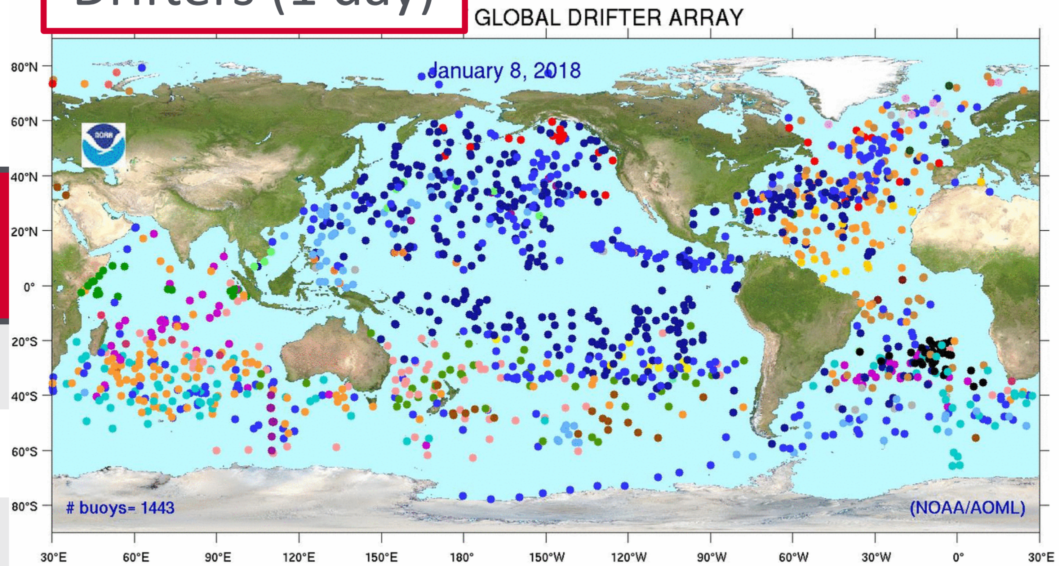


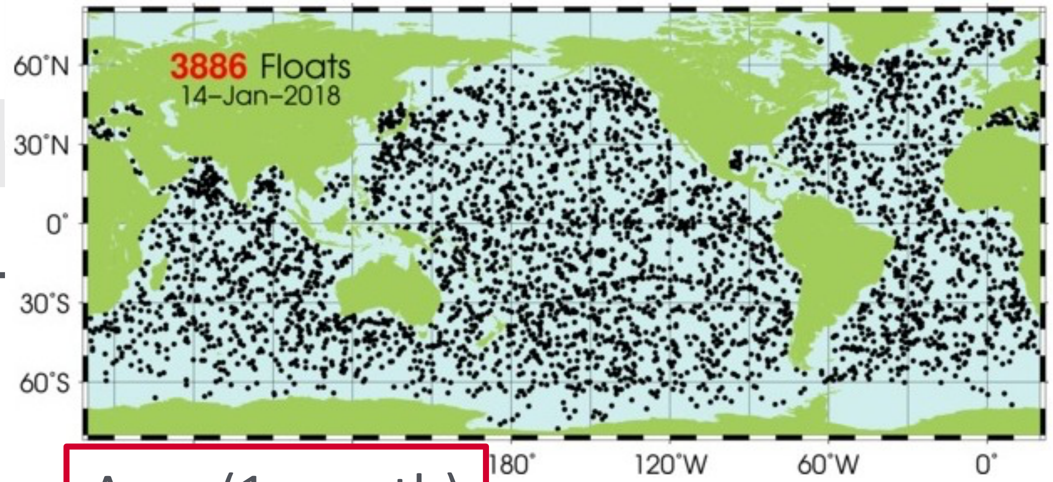
Indian Ocean mooring data, courtesy of Bob Weller, WHOI

OBSERVATIONS

Measurand	Observed by (mainly)	Variability, $\tau \geq ?$
Skin SST	IR satellite	<< hour
Skin Ice ST	IR satellite	< hour
Subskin SST	MW satellite	< hour
$\partial T_{skin} / \partial t$	Geo IR	<< hour
Depth SST	Buoy	hour
Found. SST	Argo	day+

Drifters (1 day)





Argo (1 month)

OBSERVED QUANTITIES AND THEIR CONNECTIONS

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Measurand	Observed by (mainly)	Variability $\tau \geq t$	Responds to	Controls	Informative about
Skin SST	IR satellite	<< hour	SSTz, *HF(t)*	net *HF(t)*	Depth SST
Skin Ice ST	IR satellite	< hour	Air T (<0°C)	OLR	Surf Air T
Subskin SST	MW satellite	< hour	Depth SST	Skin SST	Skin & Dpth
$\partial T_{skin}/\partial t$	Geo, buoy	<< hour	Solar, wind	--	Min. winds
Depth SST	Buoy	hour	$\int HF\,dt$, mixing	Skin & HF	All SSTs
Found. SST	Argo	day+	$\int HF\,dt$, MLT	Depth SST	ML heat

EARLIEST ANALYSIS USING SATELLITE DATA

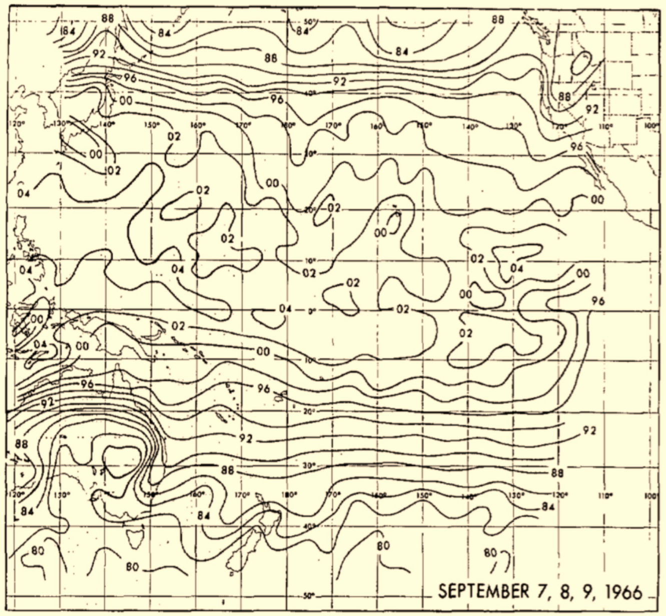


FIGURE 10.—Three-day composite Pacific Ocean surface-temperature analysis inferred from Nimbus 2 HRIR data. Isotherms are labeled in degrees Kelvin with the first digit deleted. (Add 300 to values <10; add 200 to values >10.)

Smith, W. L., P. K. Rao, R. Koffler, and W. R. Curtis, 1970: "The Determination of Sea-Surface Temperatures from Satellite High Resolution Infrared Window Radiation Measurements," Monthly Weather Review, Vol. 98, pp. 604-611.

3-day surface T analysis
across Pacific
centred on 8 Sep 1966

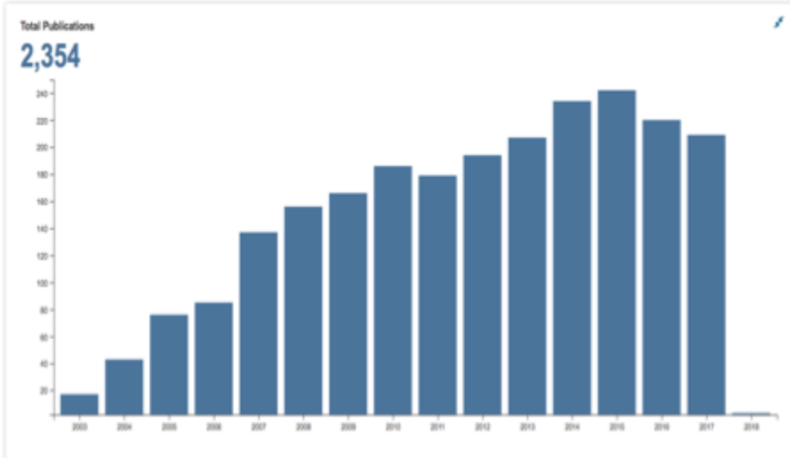
Star Trek
"The Man Trap"

REYNOLDS OISST

NOAA 1^{o} weekly OI SST

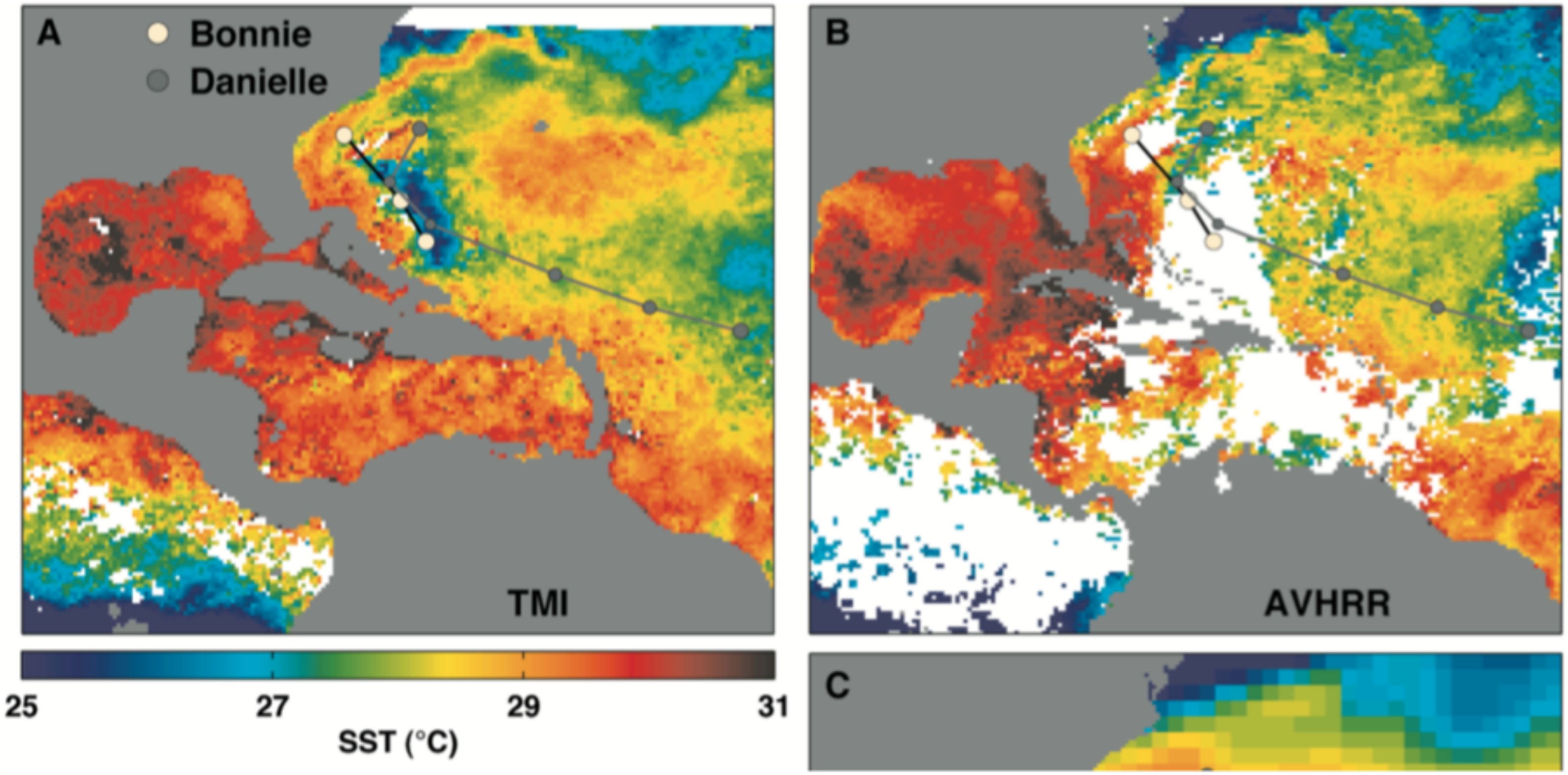
- AVHRR data,
- routine since 1993.

Reynolds et al. (2002) >2350 citations



Daily 0.25 deg OISST v2 ongoing as primary analysis in ‘Reynolds SST” family.

MICROWAVE SST

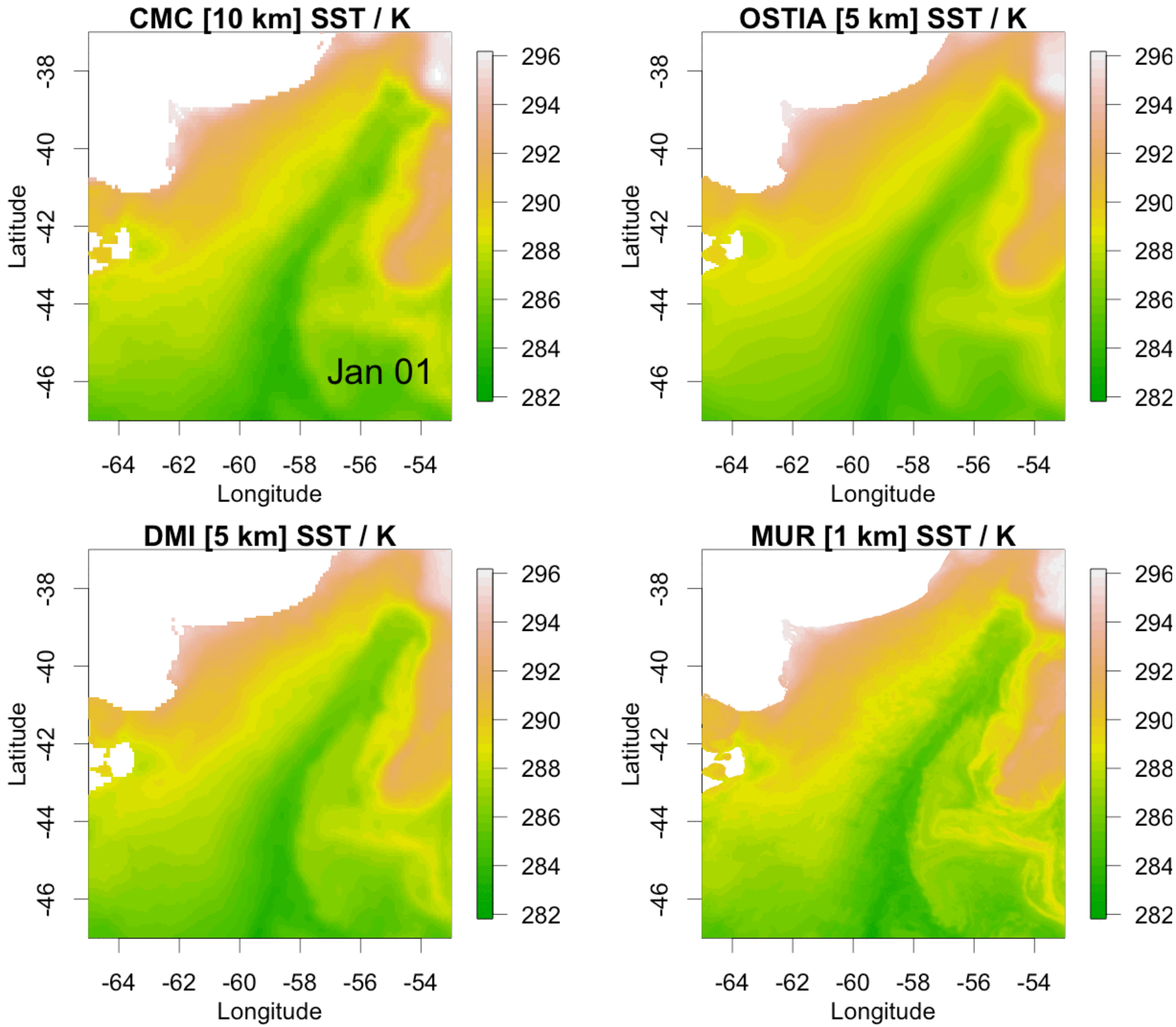


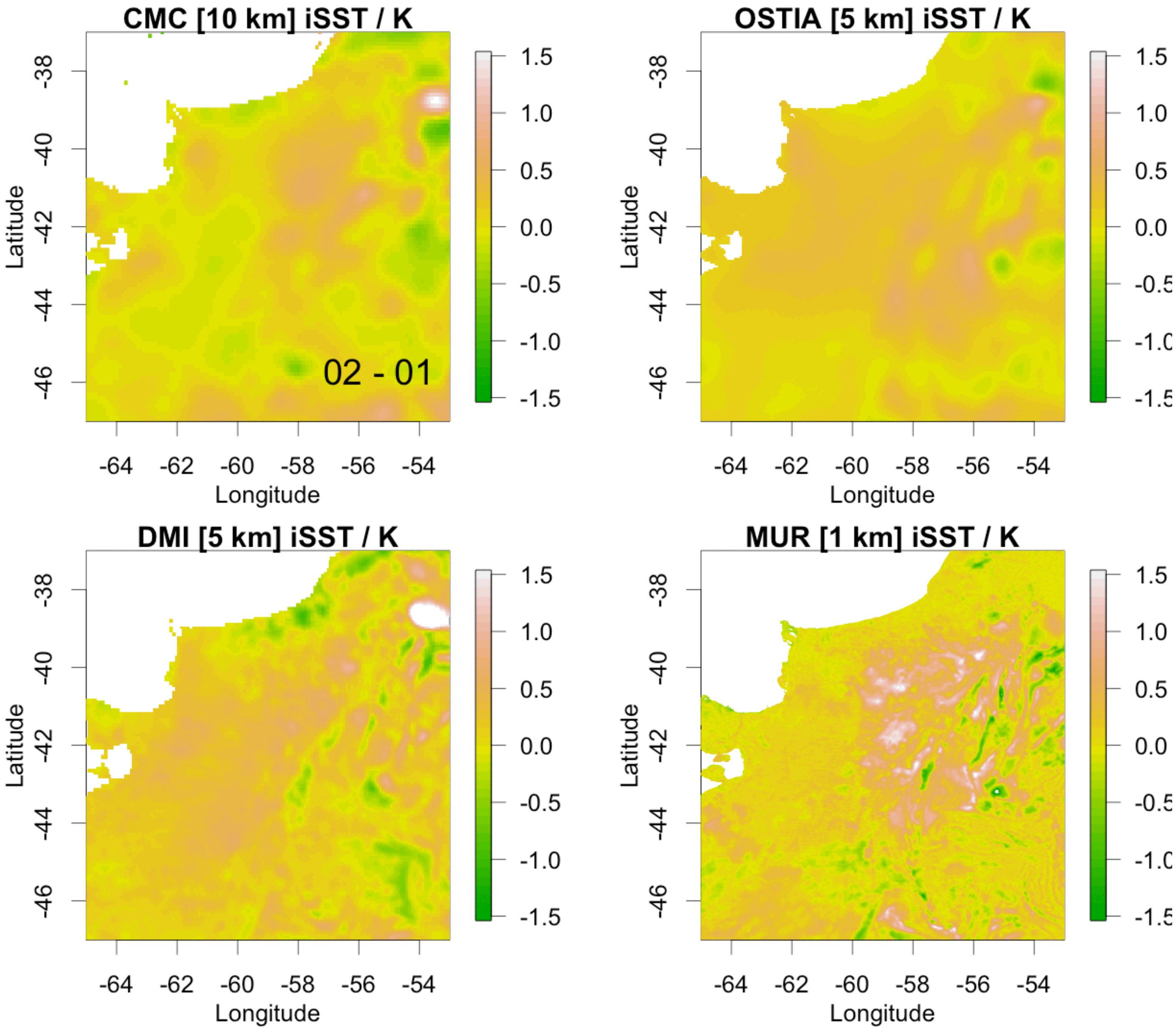
- Wentz et al, Science, 2000

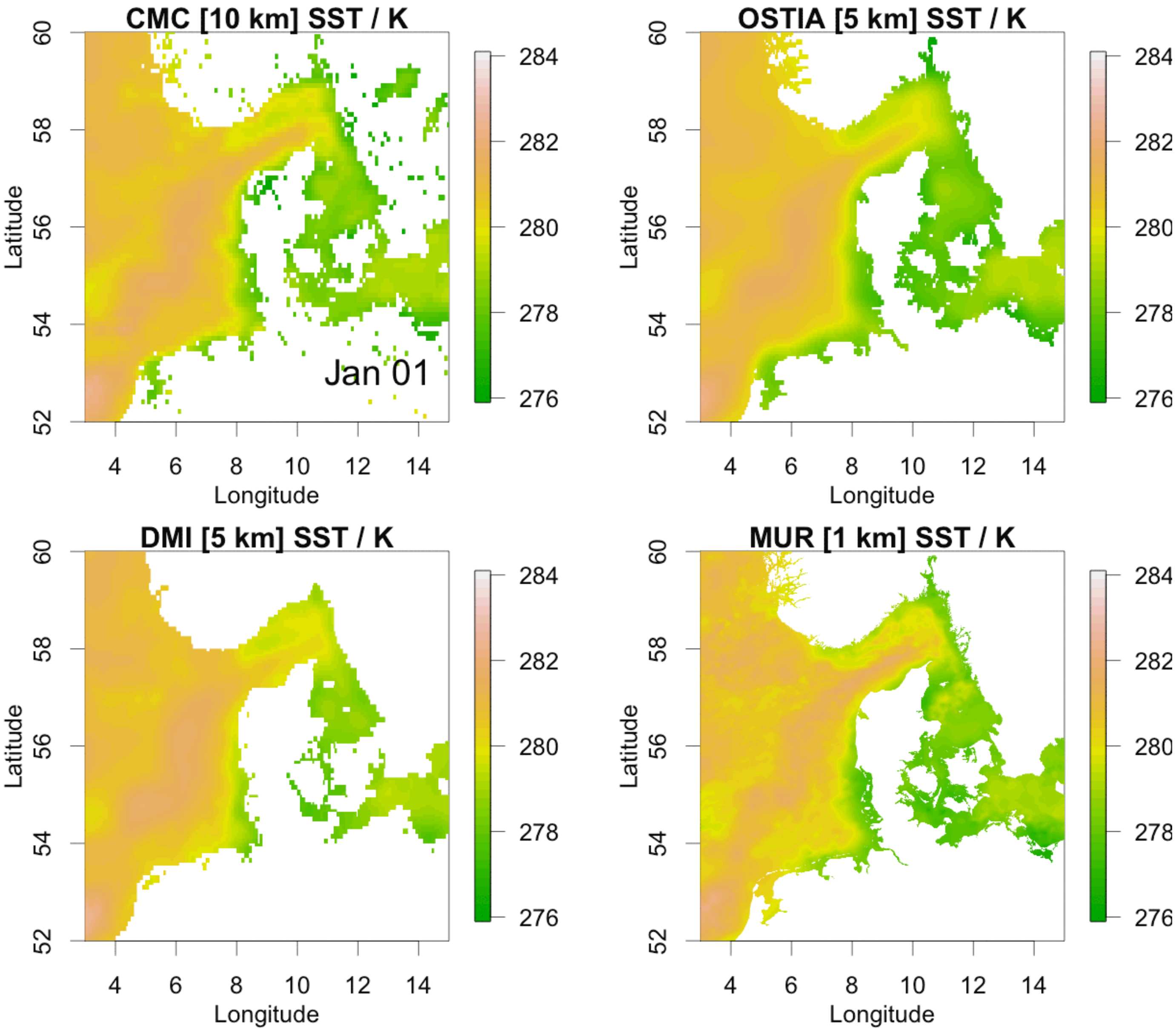
NRT GLOBAL DAILY ANALYSES

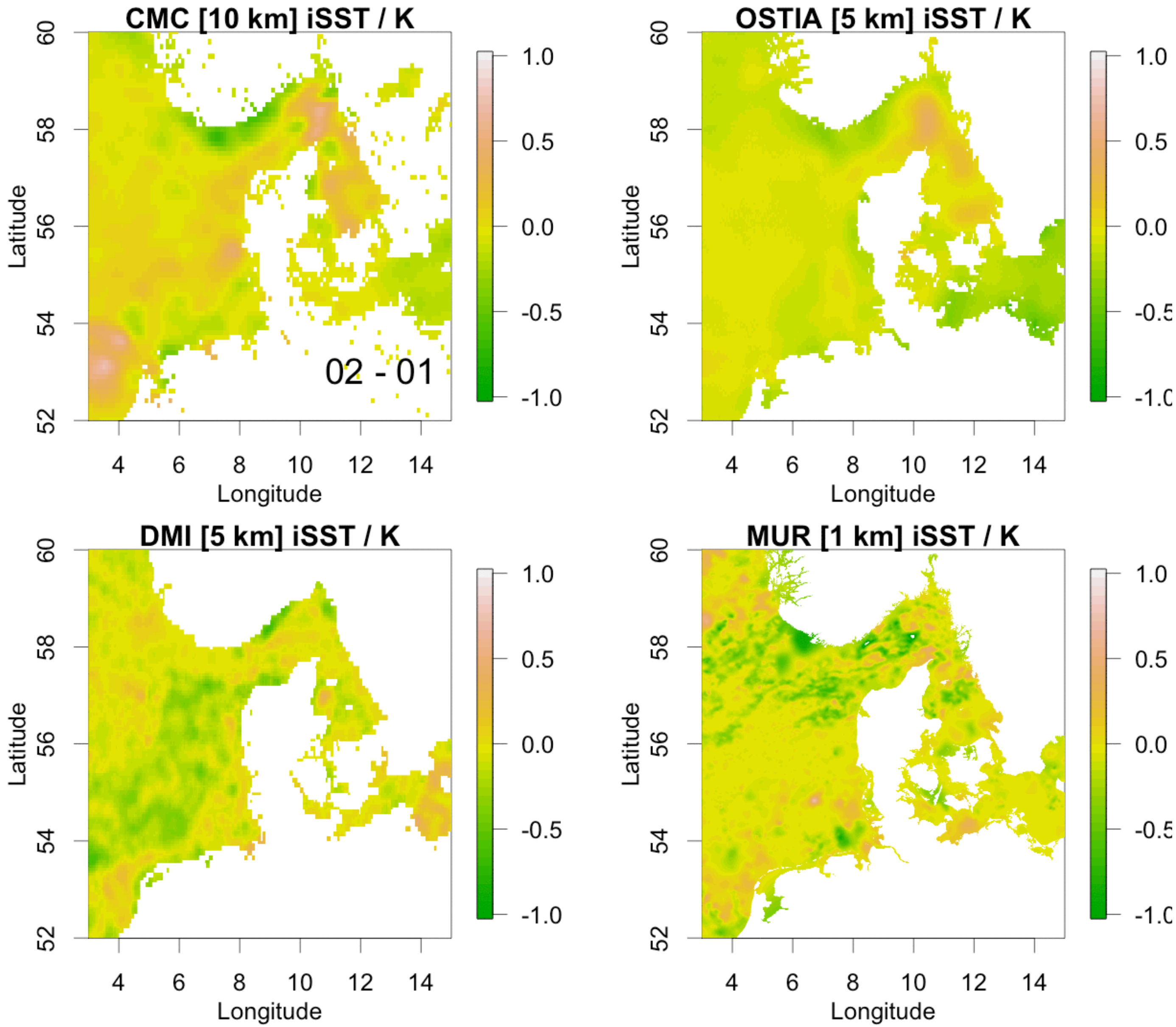
Analysis	Country	Version	Gridding	Measurand	Start	Earliest version
CMC	Canada	v3	0.1 deg	Foundation	2016	1991
DMI OI	Denmark	v1	0.05 deg	Foundation	2013	--
MUR	US (JPL)	v4	0.01 deg	Foundation	2002	2002
Reynolds OI	US (NOAA)	v2	0.25 deg	*Drifters*	1981	1981
GEO-POL	US (NOAA)	v1	0.05 deg	Foundation	2014	--
MW OI	US (REMSS)	v5	0.25 deg	Subskin	1998	1998
OSTIA	UK	v2	0.05 deg	Foundation	2013	1985
NAVO	US (Navy)	--	0.1 deg	1 m SST	2008	--
GAMSSA	Australia	--	0.25 deg	Foundation	2008	--

summary of global L4 data at podaac-ftp.jpl.nasa.gov


CMC [10 km] SST / K
OSTIA [5 km] SST / K
DMI [5 km] SST / K
MUR [1 km] SST / K
Jan 01
Latitude
Longitude
-38
-40
-42
-44
-46
-64
-62
-60
-58
-56
-54
296
294
292
290
288
286
284
282

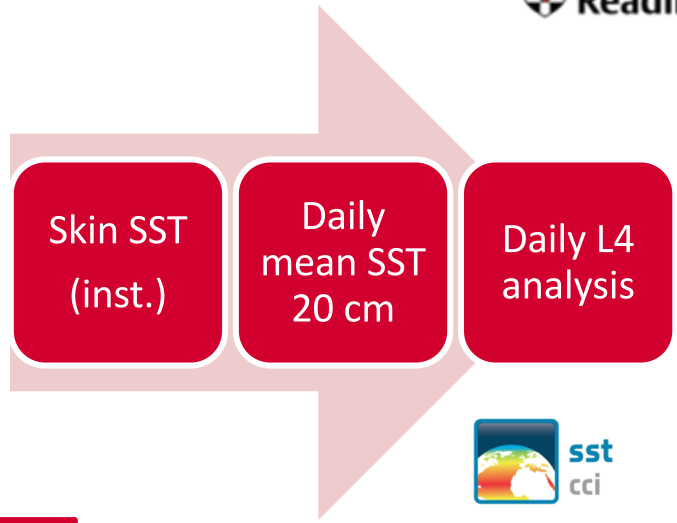

CMC [10 km] iSST / K
OSTIA [5 km] iSST / K
DMI [5 km] iSST / K
MUR [1 km] iSST / K
02 - 01
Latitude
Longitude
-38
-40
-42
-44
-46
-64
-62
-60
-58
-56
-54
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5


CMC [10 km] SST / K
OSTIA [5 km] SST / K
DMI [5 km] SST / K
MUR [1 km] SST / K
Jan 01
Latitude
Longitude
52
54
56
58
60
4
6
8
10
12
14
276
278
280
282
284


CMC [10 km] iSST / K
OSTIA [5 km] iSST / K
DMI [5 km] iSST / K
MUR [1 km] iSST / K
02 - 01
Latitude
Longitude
60
58
56
54
52
4
6
8
10
12
14
1.0
0.5
0.0
-0.5
-1.0

ANALYSIS OF SST

$$x_t = f(x_{obs}, x_{t-1}, x_{clim})$$



Definition of measurand:

Time: UTC-daily mean, 00Z, 06Z, …

Depth: skin, depth ~ 20 cm, foundation

Area/resolution

ANALYSIS OF SST

$$x_t = f(x_{obs}, x_{t-1}, x_{clim})$$

IR *vs* MW *vs* IR+MW
Polar *vs* Polar+GEO

Satellite+Buoys *vs* Buoys+Ships *vs* Satellite only …
Argo reserved for independent validation

Signal and error correlation length scales …
Relative weights, reflecting uncertainty …

ANALYSIS OF SST

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$$x_t = f(x_{obs}, x_{t-1}, x_{clim})$$

Assumptions, e.g.:

Anomaly persistence
Weight
Relaxation timescale

STATISTICAL VALIDATION

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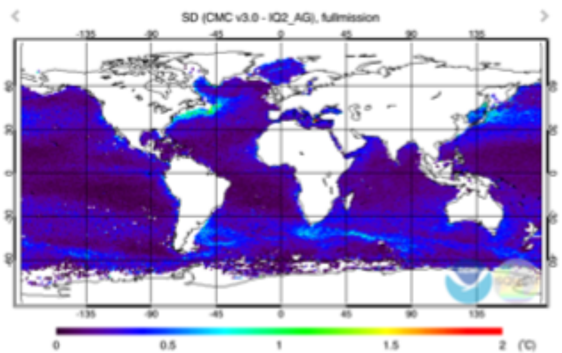
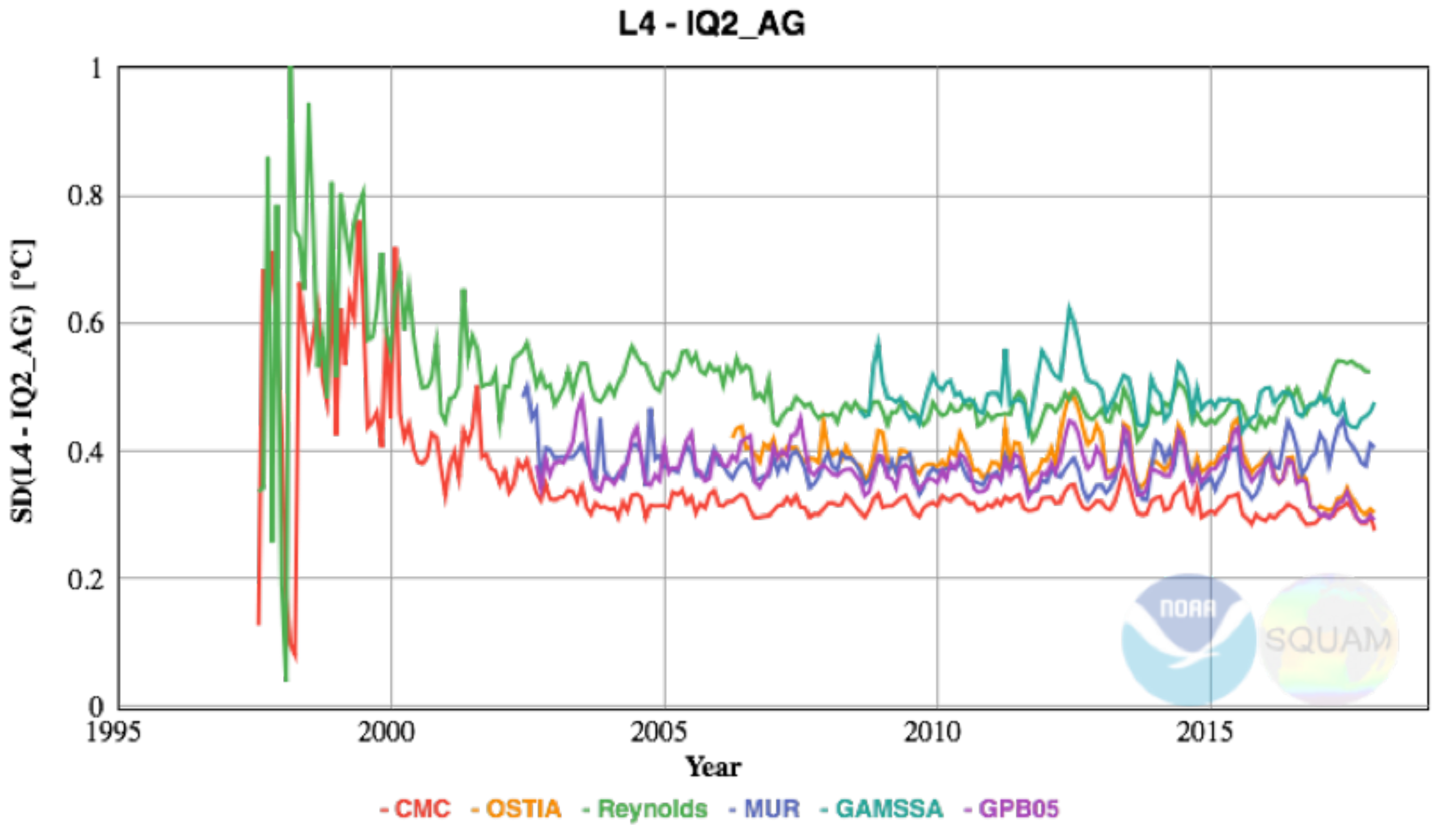
Most objective against independent observations: Argo





Tools to compare SST products at https://www.star.nesdis.noaa.gov/sod/sst/squam/index.php

SPECTRAL ANALYSIS

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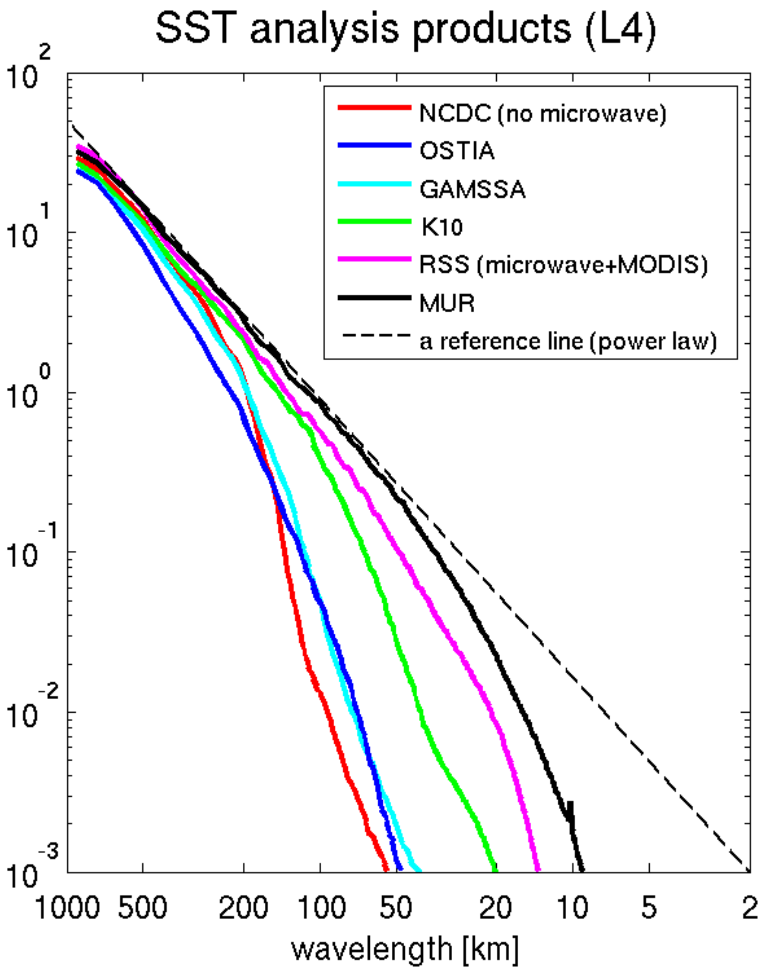


- Power spectra comparisons against against power scaling law
- Relates to the smoothness of L4
- But a “good” power spectrum does not guarantee the fine features are real
- Systems can generate small-scale noise (e.g. Reynolds et al, 2013)

Analysis by M Chin, JPL (MUR team)

WHAT MEASURAND?

- Need a clear definition of the target measurand
- Use understanding of how different “SSTs” relate

- Foundation SST
  - Widely used. Daily quantity.
  - Can differ from SST ”seen” by the atmosphere. Very sparsely observed.

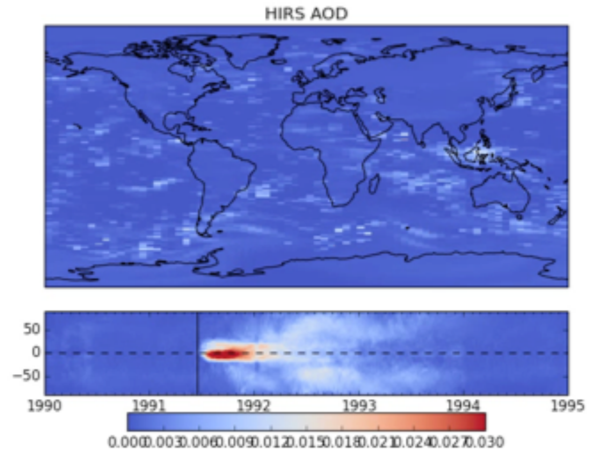
- SST 20 cm (“drifter depth”)
  - SST CCI chose this for compatibility with centennial record (closer to buckets)
  - We adjust for skin effect, stratification and time of observation within diurnal cycle

- Skin SST analysis (sub-daily / diurnal analysis)

INFRA-RED SST OBSERVATIONS

- Continuity with high quality instruments

- Dual-view and/or multi-spectral IR sensors as reference sensors
  - VIIRS, SLSTR soon!
  - Requires global low biases
  - Including under a variety of aerosol conditions



IR aerosol optical depth.
Pinatubo event in 1991

NCEO: Embury

MICROWAVE SST OBSERVATIONS

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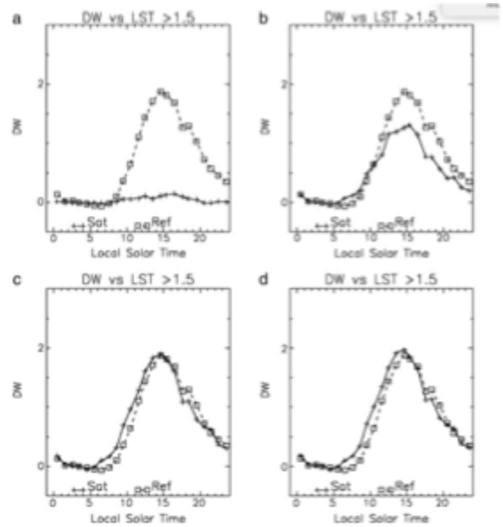
- MW SST continuity is not secure

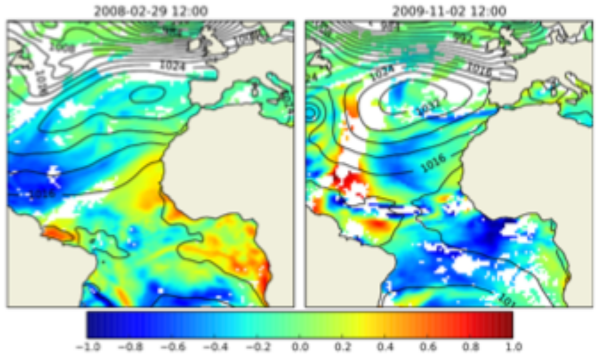
- Persistent cloud regions
  - MW SST can have a crucial impact in situations of SST features evolving during persistent cloud
- Coastal zone impact
  - Beam-forming to get within 100 km accurately
- Global quality impact
  - Radiometric challenge to get $\sigma_{SST} < 0.3$ K
  - Current brightness temperature noise (e.g. AMSR-2) imply limit $\sigma_{SST} \sim 0.4$ K
  - Information content limit of the channels is $\sigma_{SST} \sim 0.1$ K (Pearson et al., 2018)

USE OF IR/MW/(SUB)SKIN SST

- Diurnal variability (skin) ~ 0.1 to 1.0 K (extreme, ~5 K)
  - IR SSTs are variable in their ability to reflect full amplitude
- Locally correlated, variable SST errors ~ 0.3 K
  - Not yet well characterised
- Inter-satellite biases (non-reference) ~ 0.1 to 0.3 K
  - Ongoing work e.g. in SST CCI
- Challenge of partitioning these effects appropriately within analysis system



Above: different algorithms with differential DV sensitivity. Below: example snapshots of IR SST error on different days.



SST ANALYSIS

- Evaluating the true feature resolution compared to grid resolution
- Methods that adapt the attempted feature resolution to the observation information content

- How to compare and judge between analysis fields?
- What are the limits of purely data/statistical approaches? Are users' needs met without additional dynamical constraints?