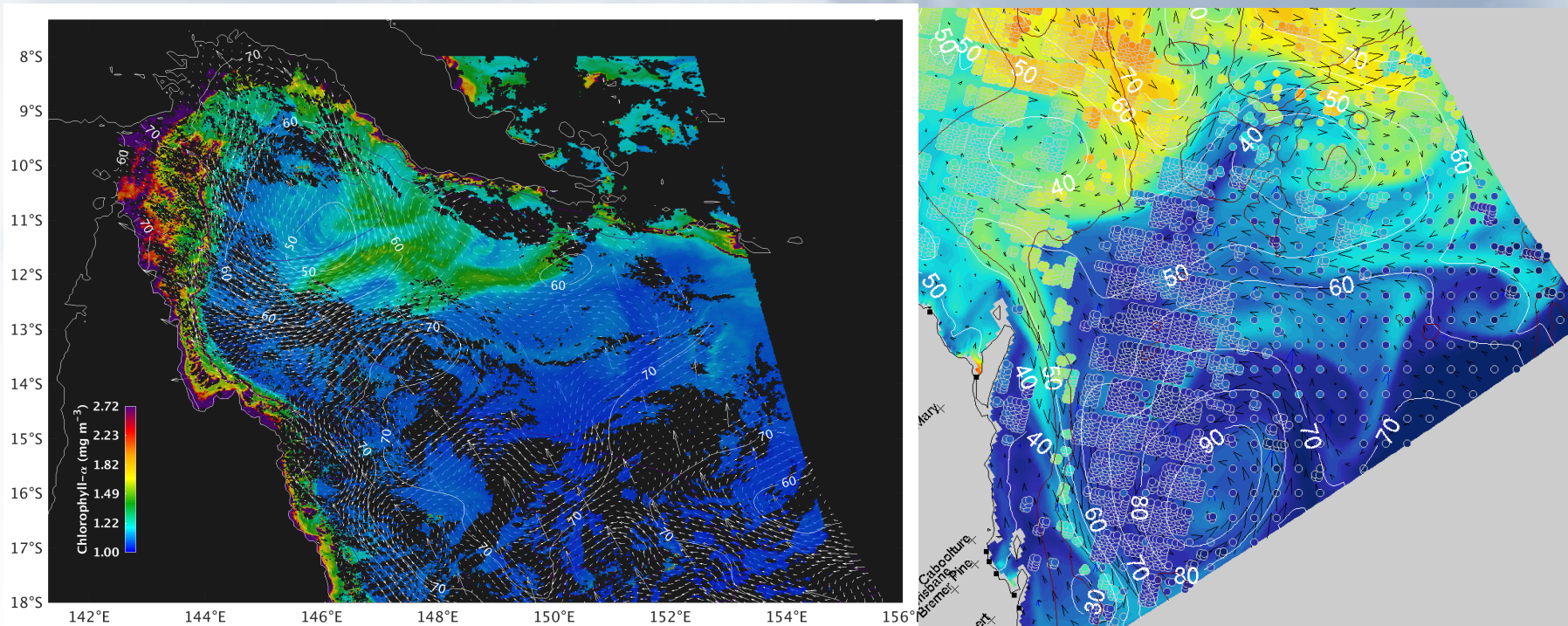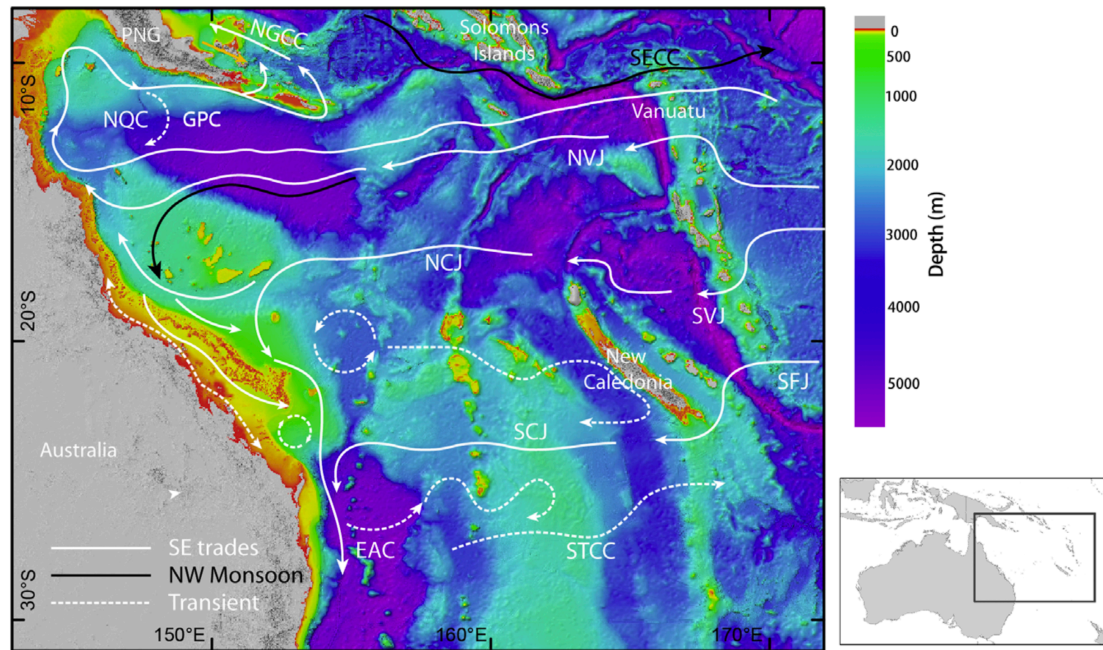# Ocean forecasting and reanalysis using ROMS with ensemble data assimilation

Paul Sandery, Gary Brassington, Frank Colberg, Pavel Sakov

Fig. 1. Bathymetry and key currents in the Great Barrier Reef region NGCC: New Guinea Coastal Current, mirroring the deeper New Guinea Coastal Undercurrent; NQC: North Queensland Current which is part of the Gulf of Papua Current (GPC); SECC: South Equatorial Countercurrent; Jets of the South Equatorial Current (SEC): NVJ: North Vanuatu Jet; NCJ: North Caledonia Jet; SVJ: South Vanuatu Jet; SFJ: South Fiji Jet; SCJ: South Caledonia Jet; EAC: East Australian Current; STCC: Subtropical Countercurrent; A wind-driven coastal current is shown running parallel to the coast along the inner shelf; (bathymetry data courtesy of deep.reef.org, Beaman (2010)).

REANALYSIS 2006-2015
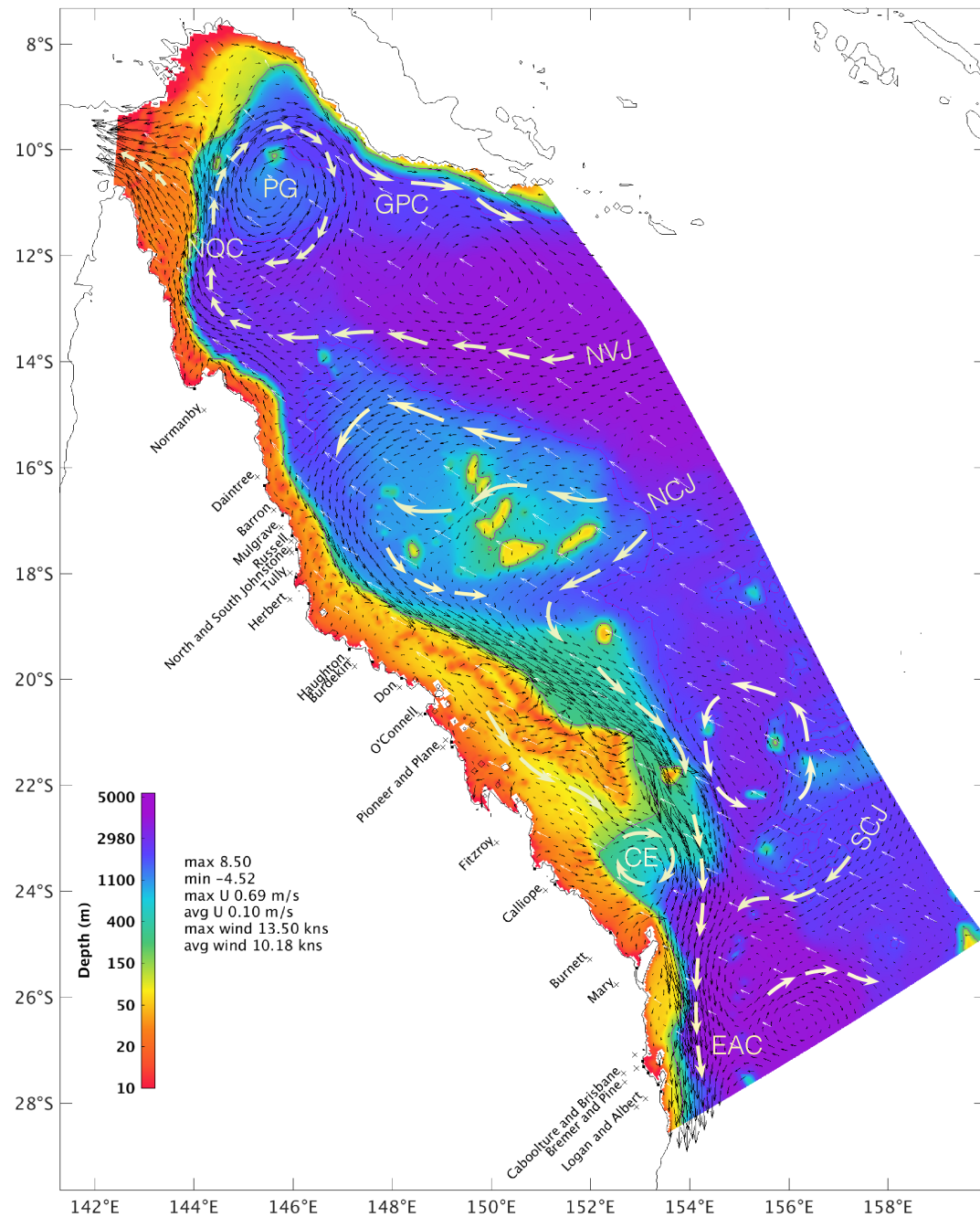
- ROMS ~4km curvilinear grid, 30 levels

- Bathymetry blend of GBR100m, GA 9-arcsec and GA northward extension

- Atmospheric forcing from NCEP Climate Forecast System Reanalysis (CFSR)

- Tidal forcing TPX07

- Rivers BoM hydrological gauge observations

- Nested in BRAN

- Hindcast

- Generate background ensemble model error covariances
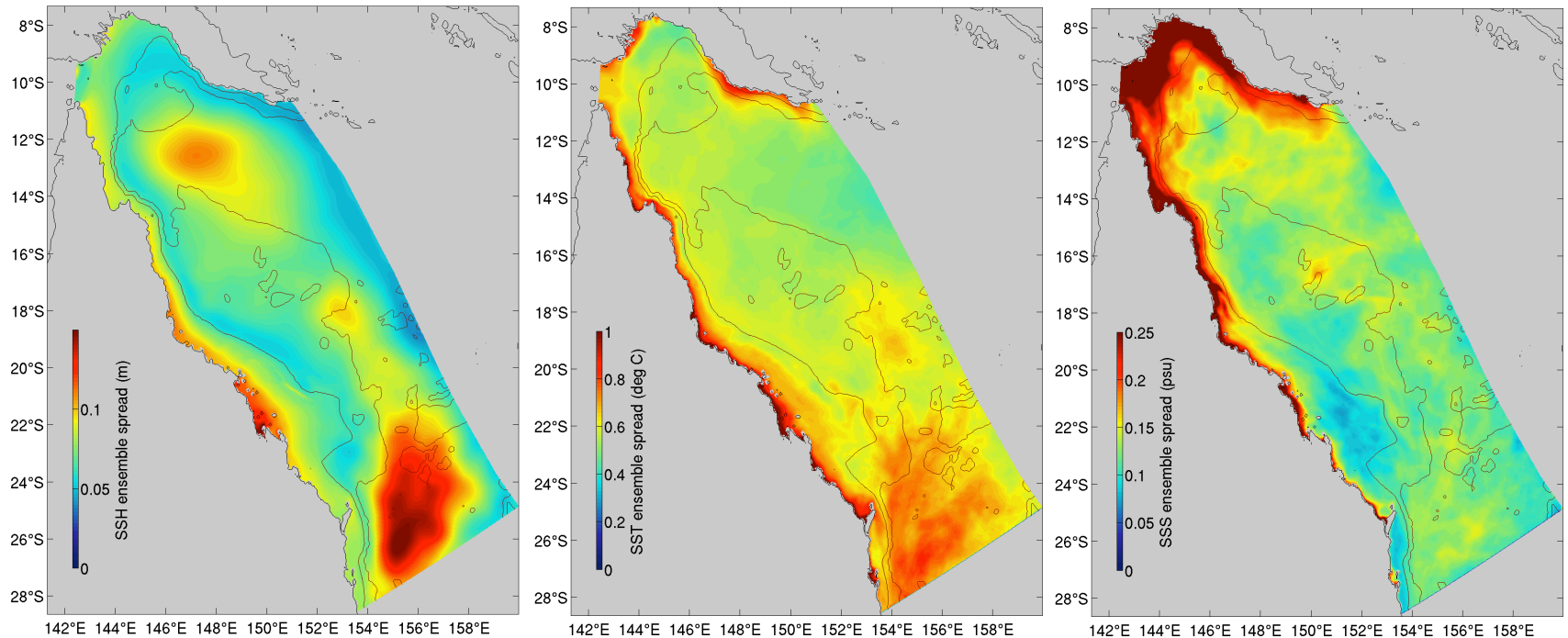
- EnOI FGAT using ENKF-C code

Data Assimilation

$$\mathbf{x}^a = \mathbf{x}^f + \mathbf{K}\left[\mathbf{y} - \mathcal{H}(\overline{\mathbf{x}}^f)\right], \qquad\qquad (1a)$$

$$\mathbf{K} = \mathbf{B}\mathbf{H}^{\mathrm{T}}\left[\mathbf{H}\mathbf{B}\mathbf{H}^{\mathrm{T}} + \mathbf{R}\right]^{-1}, \qquad\qquad (1b)$$

$$\mathbf{B} \equiv \mathbf{A}\mathbf{A}^{\mathrm{T}}\left[(\mathbf{m} - \mathbf{1})\right]^{-1}, \qquad\qquad (1c)$$
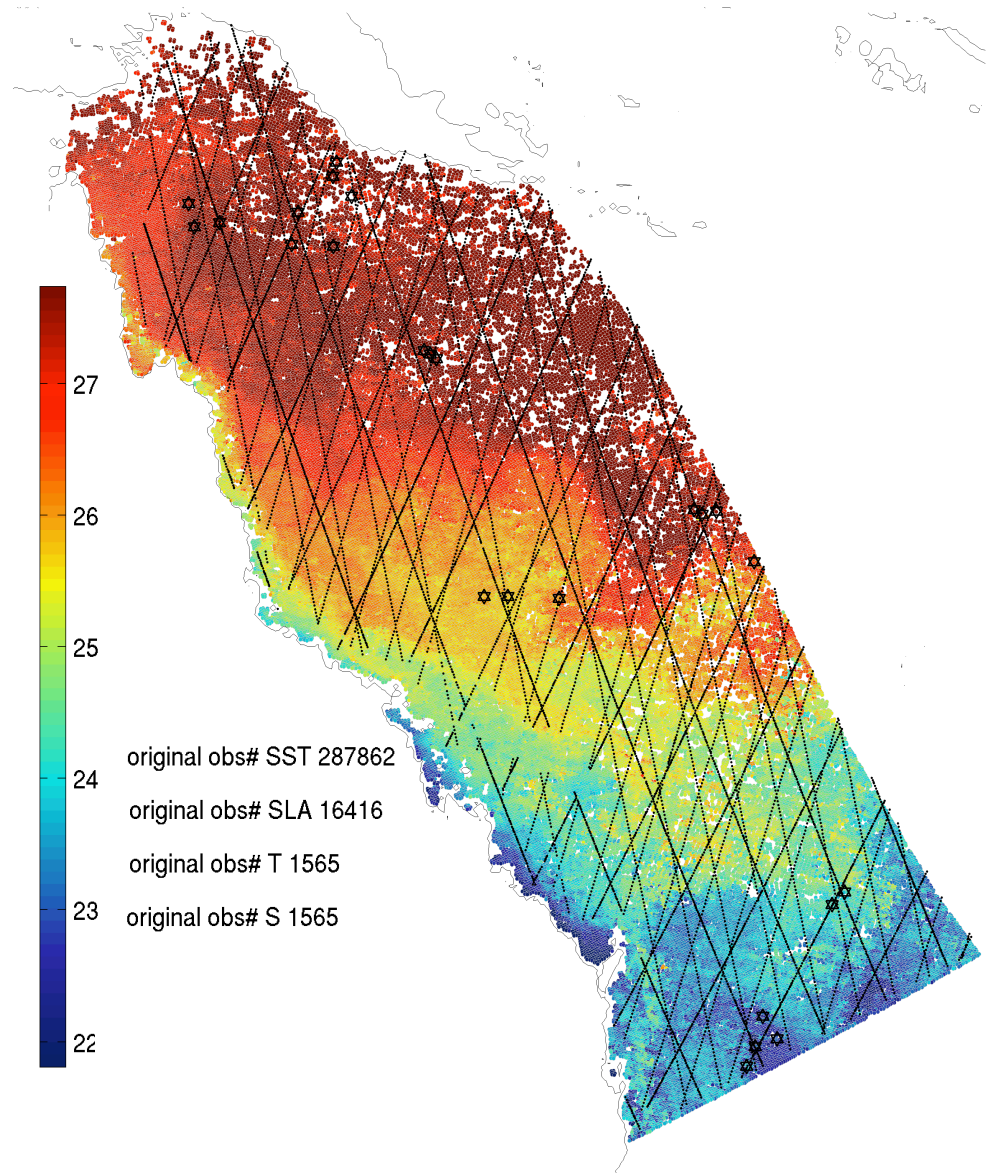
- Anomalies are 255 member ensemble of centred 3 day minus 30 day running means from hindcast

Observations

- Along track altimetry from RADS database

- Infrared and Microwave SST from Pathfinder, AVHRR, AMSR-E, AMSR2, WindSat

- In-situ temperature and salinity from Argo

- Super-observations

original obs# SST 287862

original obs# SLA 16416

original obs# T 1565

original obs# S 1565

Variable (units)	Observations*
SLA (cm)	1409569
SST (K)	33302676
T (K)	94912
S (psu)	93177

January 2008 super-observation composite

First Guess at Appropriate Time (FGAT) EnOI system
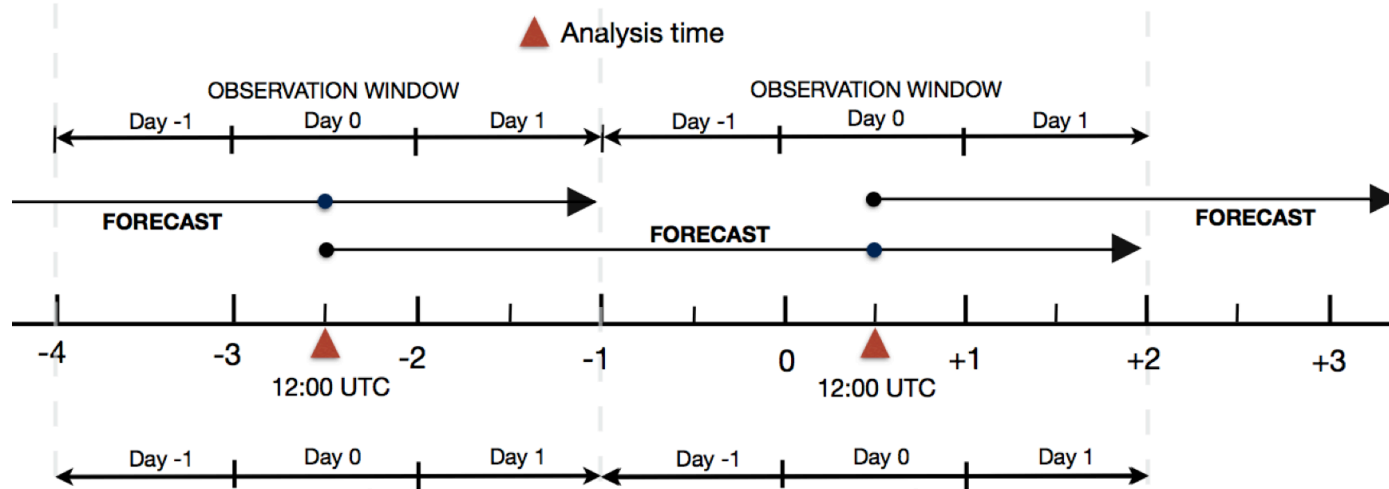
- All errors based on innovations

| region	obs.type	# obs.	|for.inn.|	|an.inn.|	for.inn.	an.inn.	for.spread	an.spread
GBR4								
	SLA	1435	0.049	0.030	-0.012	-0.003	0.081	0.081
	-1	564	0.060	0.033	-0.037	-0.012	0.090	0.090
	0	228	0.038	0.030	-0.014	-0.003	0.065	0.065
	1	643	0.044	0.027	0.011	0.004	0.079	0.079
	j1	521	0.054	0.030	-0.026	-0.009	0.079	0.079
	j2	593	0.049	0.032	0.000	0.005	0.082	0.082
	n1	314	0.042	0.025	-0.012	-0.008	0.081	0.081
	N/A	7	0.018	0.017	0.007	0.009	0.080	0.080
	SST	31332	0.350	0.237	-0.170	-0.043	0.576	0.576
	-1	11338	0.385	0.247	-0.326	-0.190	0.575	0.575
	0	10711	0.320	0.216	-0.105	0.020	0.577	0.577
	1	9283	0.343	0.249	-0.055	0.063	0.576	0.576
	AVHRR	26610	0.333	0.219	-0.140	-0.019	0.574	0.574
	WindSat	1718	0.511	0.389	-0.408	-0.254	0.596	0.596
	AMSRE	935	0.496	0.421	-0.339	-0.189	0.565	0.565
	N/A	2069	0.377	0.260	-0.284	-0.119	0.594	0.594

CYCLE 20100207

Forecasts for 21 May 2009

- SLA contours and surface currents from shown over both panels
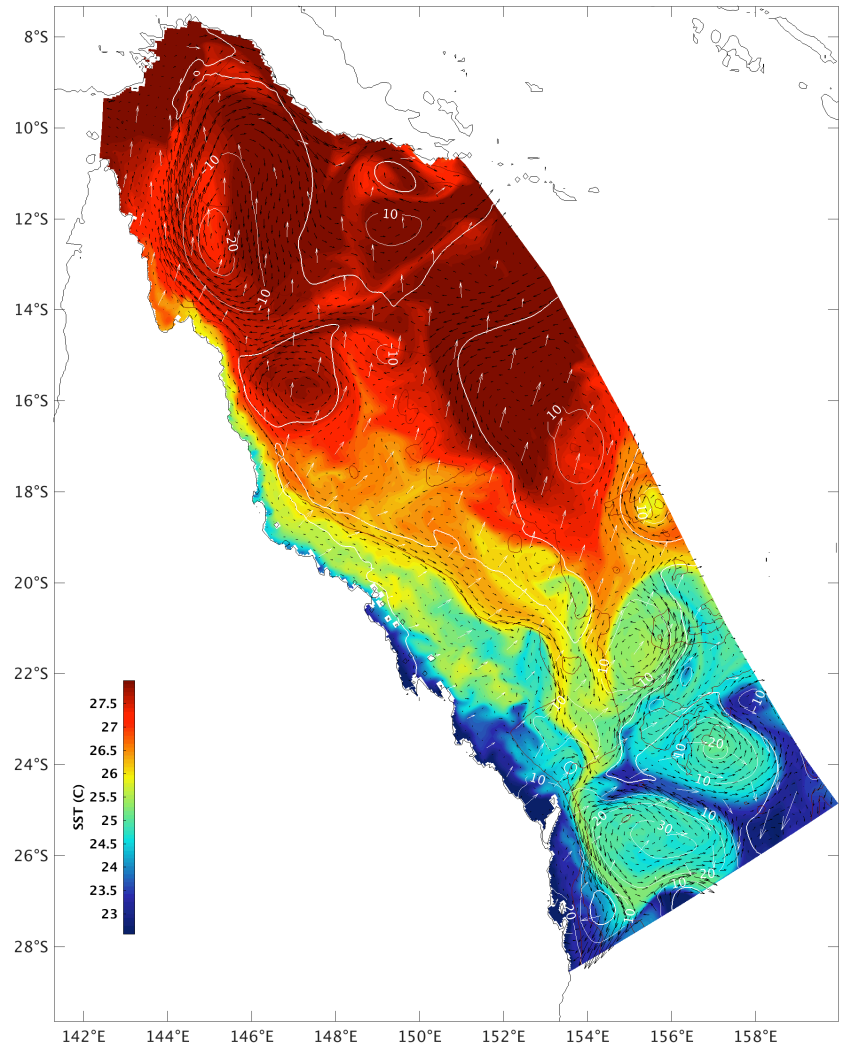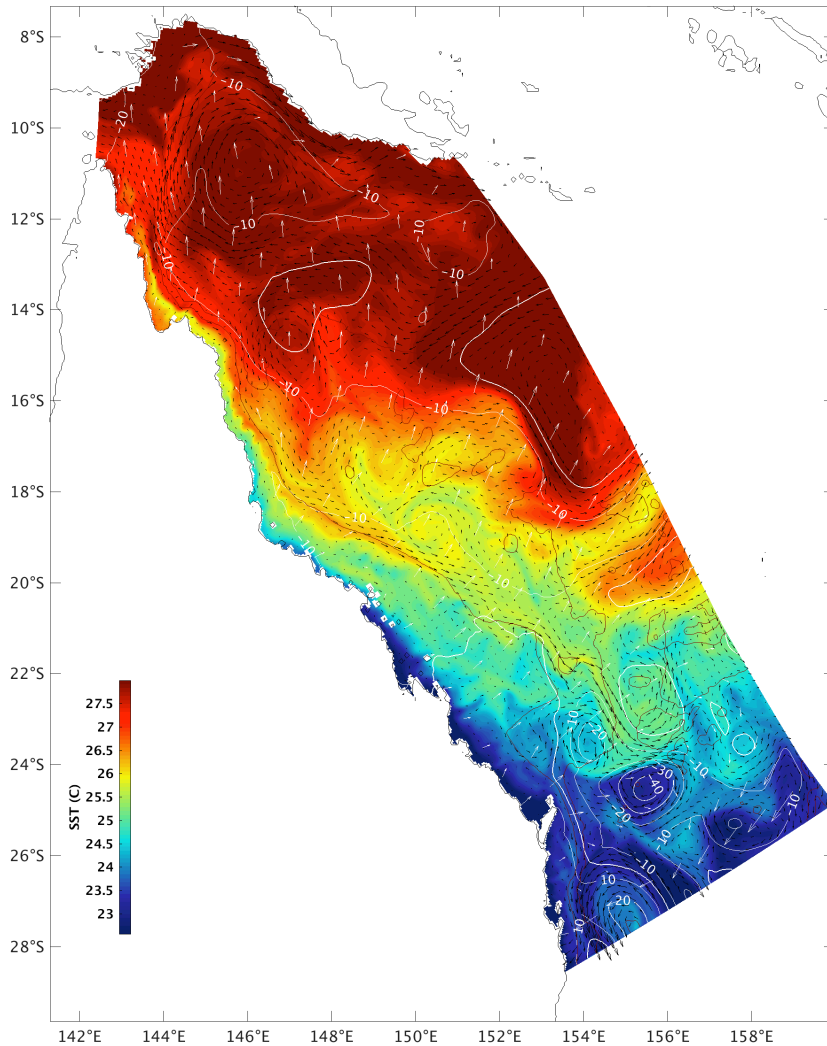
- Which is the hindcast and which is a forecast from reanalysis system?

Forecasts for 21 May 2009
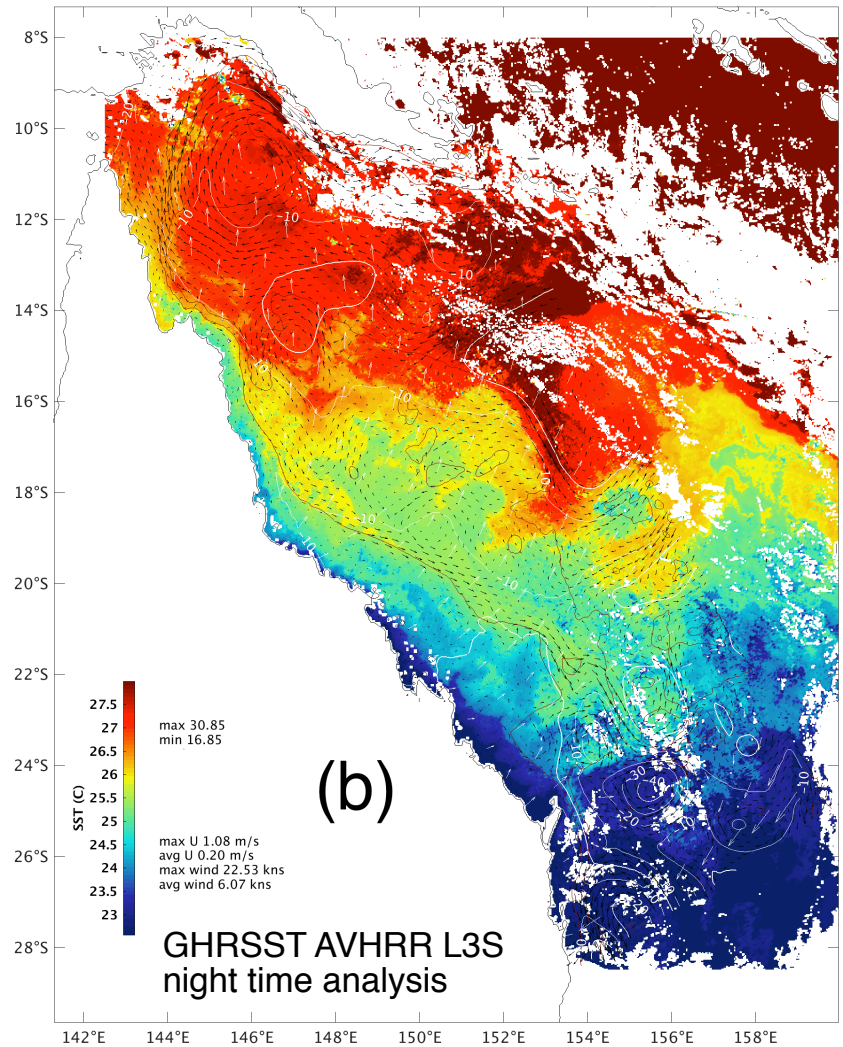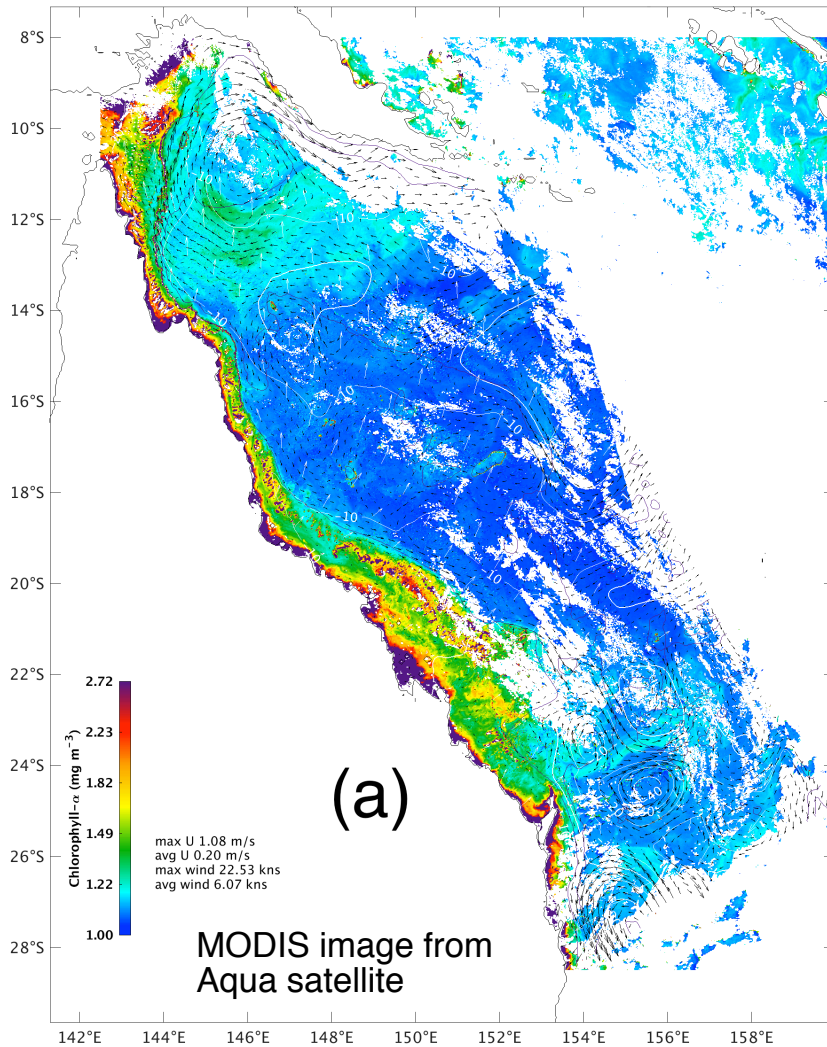
- SLA contours and surface currents from shown over both panels
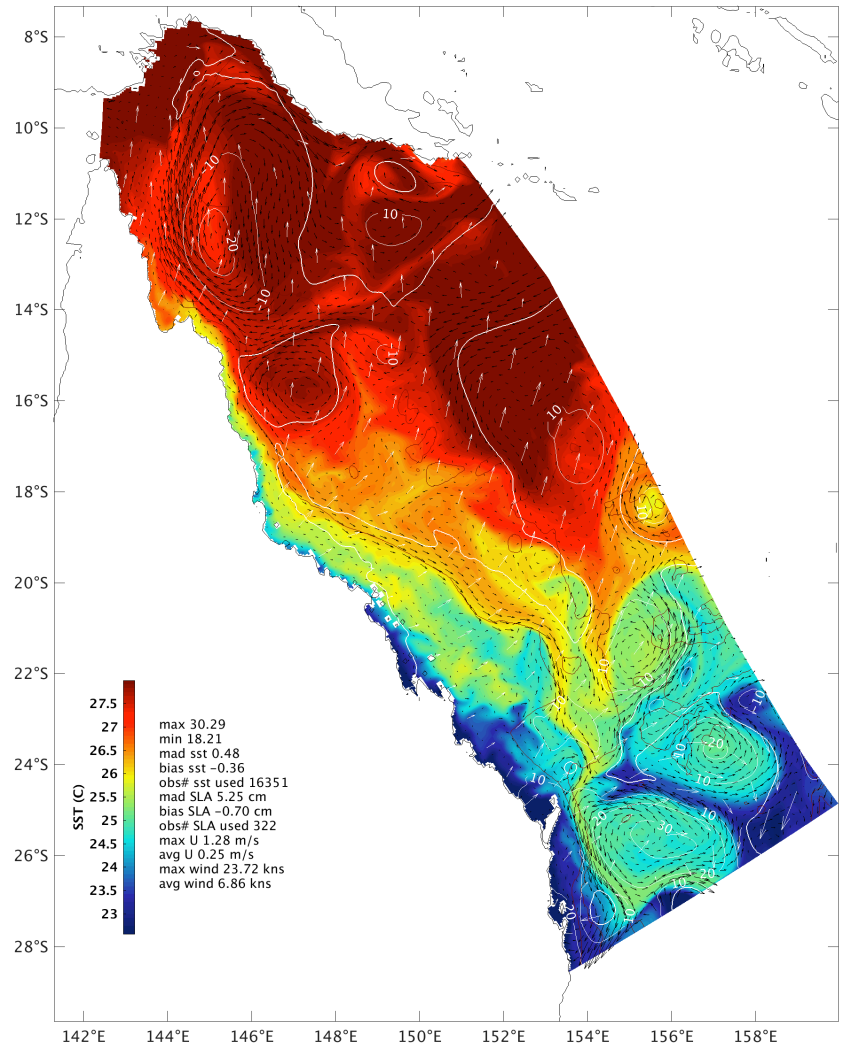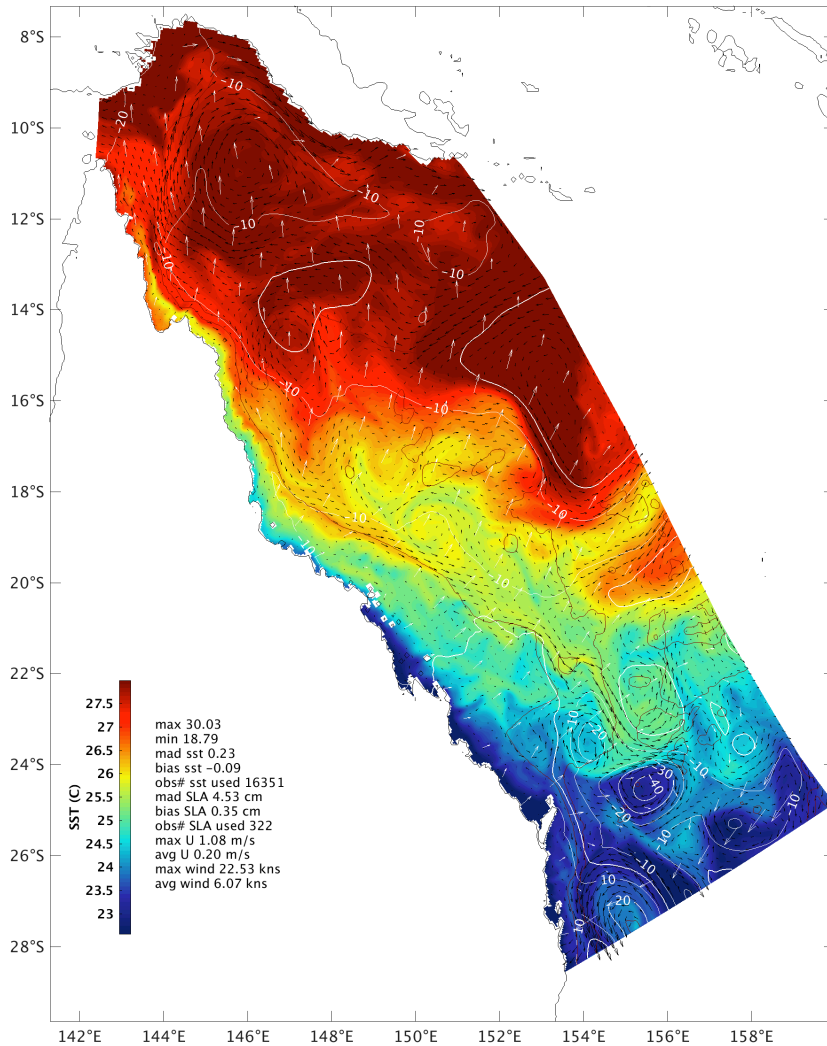
- Which is the hindcast and which is a forecast from reanalysis system?
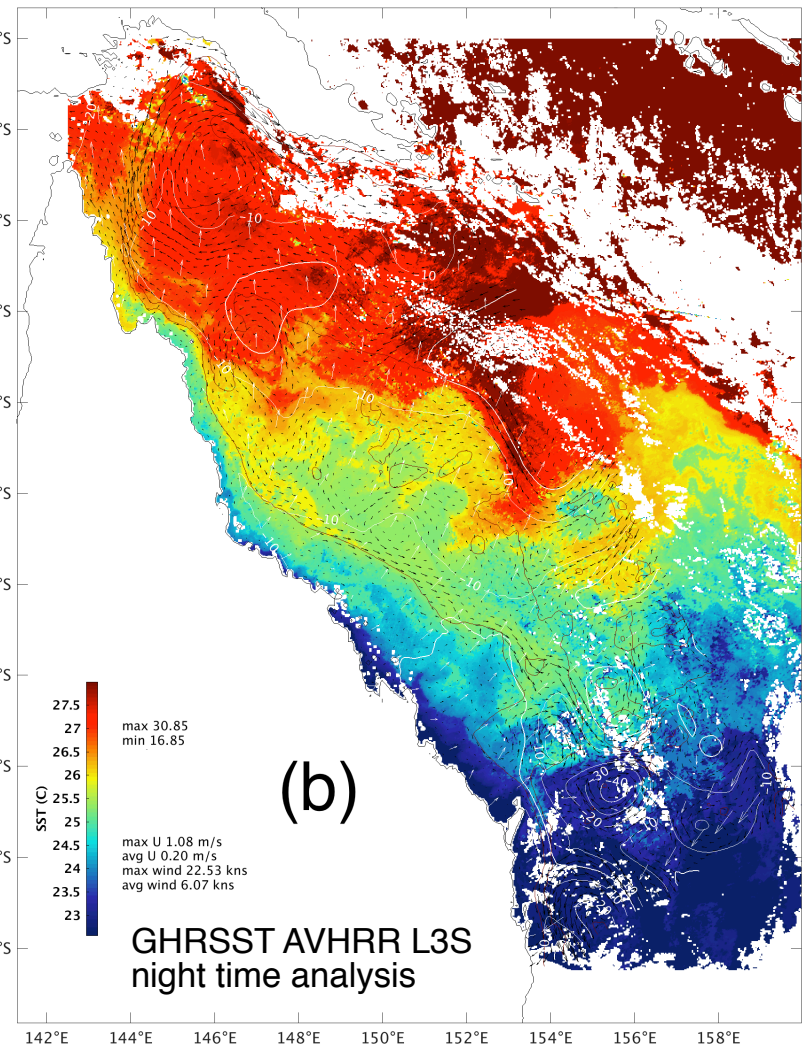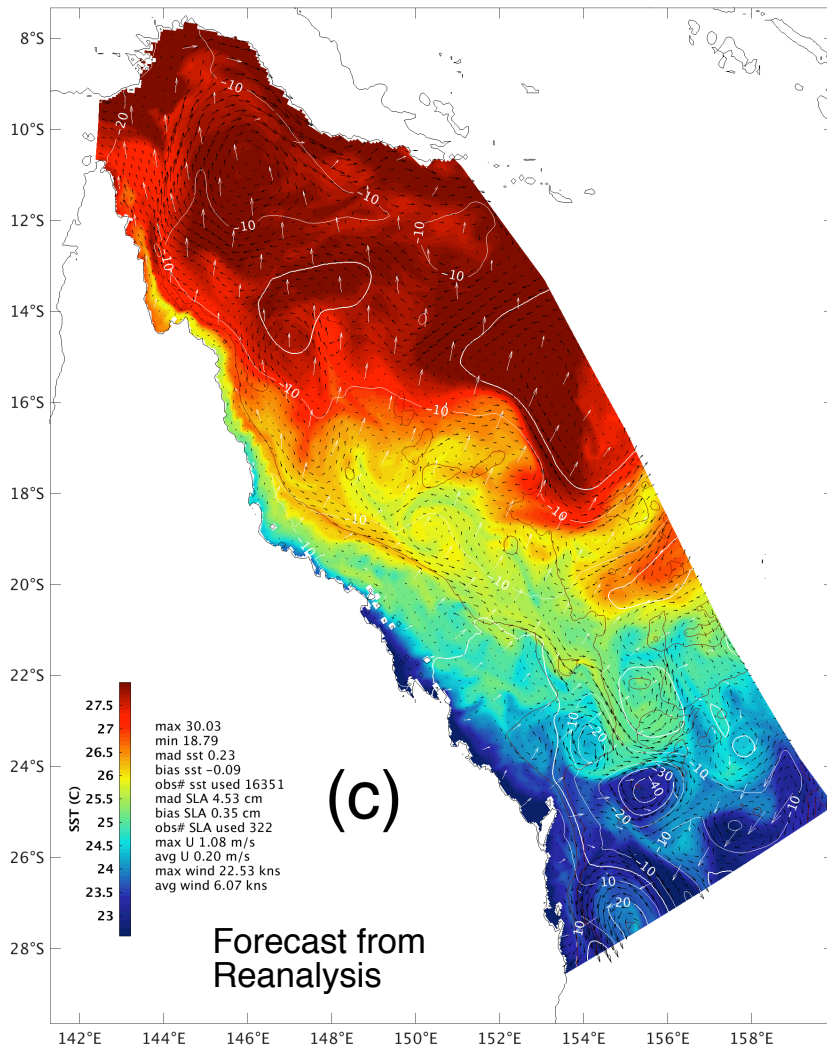
Forecast for 21 May 2009

(a) MODIS image from Aqua satellite

Chlorophyll-α (mg m⁻³)

max U 1.08 m/s
avg U 0.20 m/s
max wind 22.53 kns
avg wind 6.07 kns

(b) GHRSST AVHRR L3S night time analysis

SST (C)

max 30.85
min 16.85

max U 1.08 m/s
avg U 0.20 m/s
max wind 22.53 kns
avg wind 6.07 kns

• SLA contours and surface current from forecast with DA shown over both panels

Forecast for 21 May 2009

(c) Forecast from Reanalysis

SST (C)

27.5
27
26.5
26
25.5
25
24.5
24
23.5
23

max 30.03
min 18.79
mad sst 0.23
bias sst −0.09
obs# sst used 16351
mad SLA 4.53 cm
bias SLA 0.35 cm
obs# SLA used 322
max U 1.08 m/s
avg U 0.20 m/s
max wind 22.53 kns
avg wind 6.07 kns

(b) GHRSST AVHRR L3S night time analysis

SST (C)

27.5
27
26.5
26
25.5
25
24.5
24
23.5
23

max 30.85
min 16.85

max U 1.08 m/s
avg U 0.20 m/s
max wind 22.53 kns
avg wind 6.07 kns
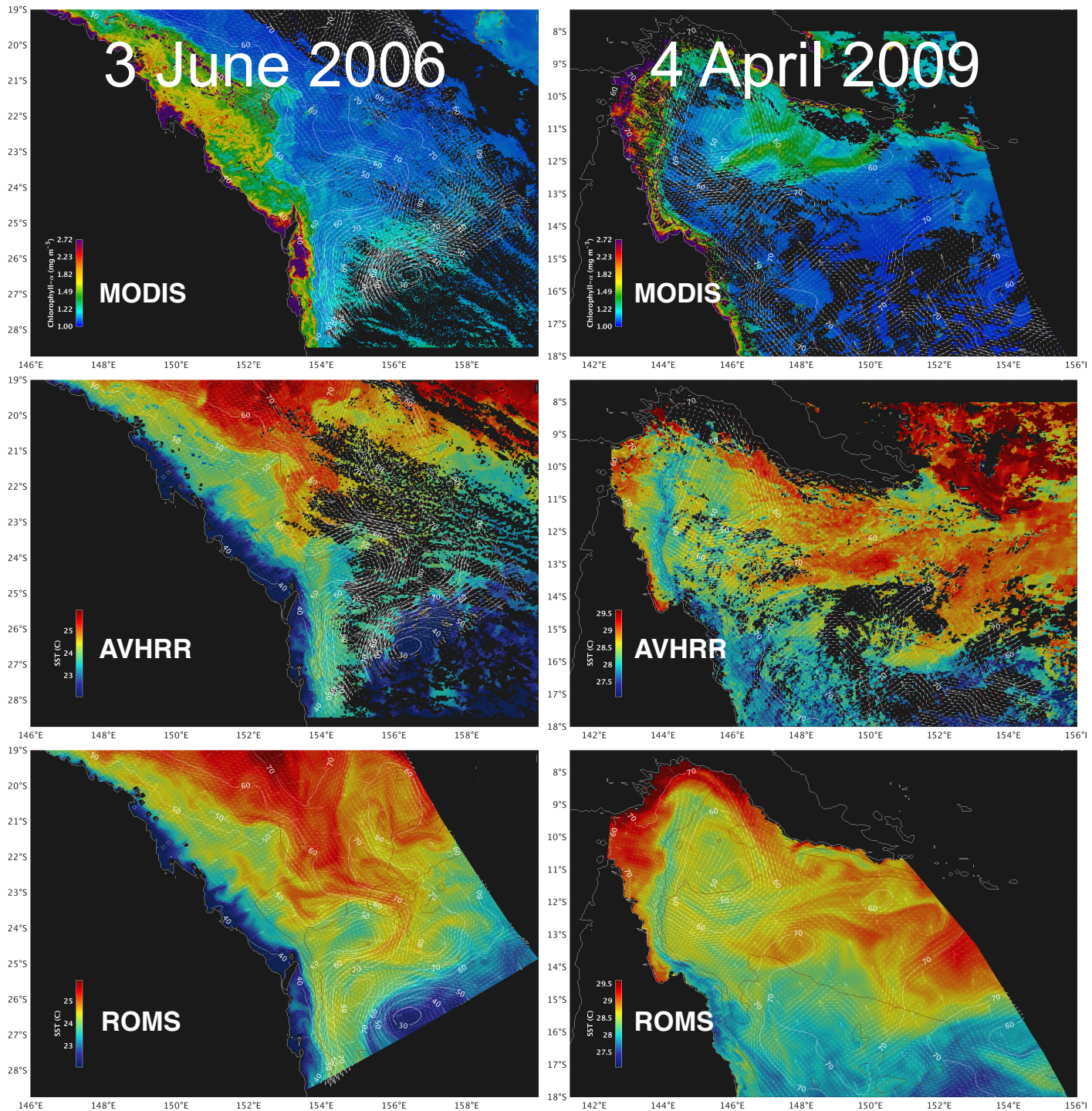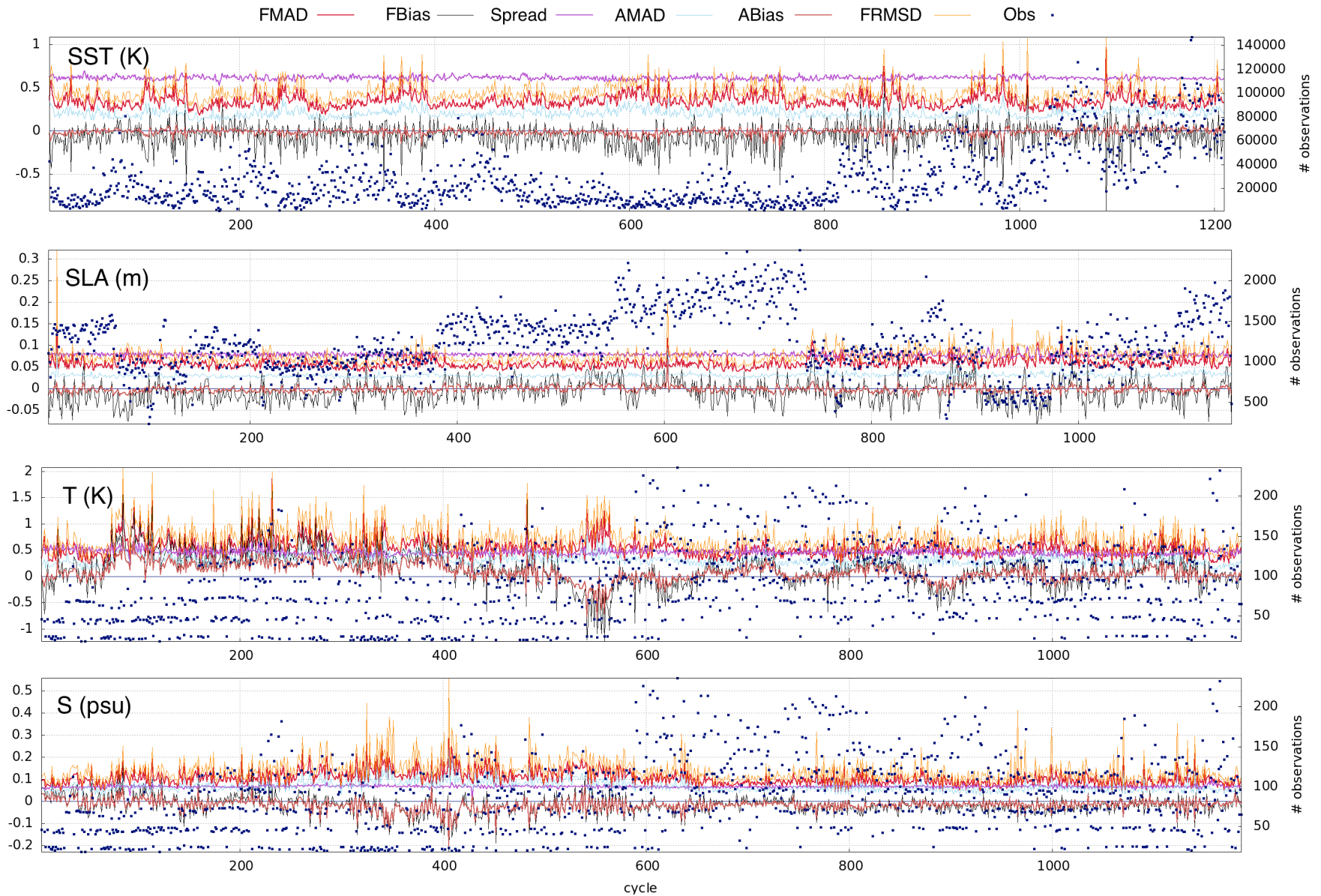
- SLA contours and surface current from forecast with DA shown over both panels

Other examples of forecasts from reanalysis system compared to satellite imagery

- SLA contours and surface currents shown over both panels

Forecast innovation errors 2006-2015

Summary - 10 years of forecast error

Table 1: Average forecast, analysis and hindcast innovation error statistics for 2006-2015. ⋆ Total number of super-observations used shown. MAD-Mean Absolute Deviation.

Variable (units)	Forecast MAD	Forecast Bias	Analysis MAD	Analysis Bias	Hindcast MAD	Hindcast Bias	Observations⋆
SLA (cm)	5.87	-0.07	3.07	-0.02	8.36	0.2	1409569
SST (K)	0.346	-0.0551	0.207	-0.013	0.54	-0.238	33302676
T (K)	0.535	0.142	0.315	0.083	0.78	0.202	94912
S (psu)	0.102	-0.015	0.067	-0.016	0.133	-0.032	93177
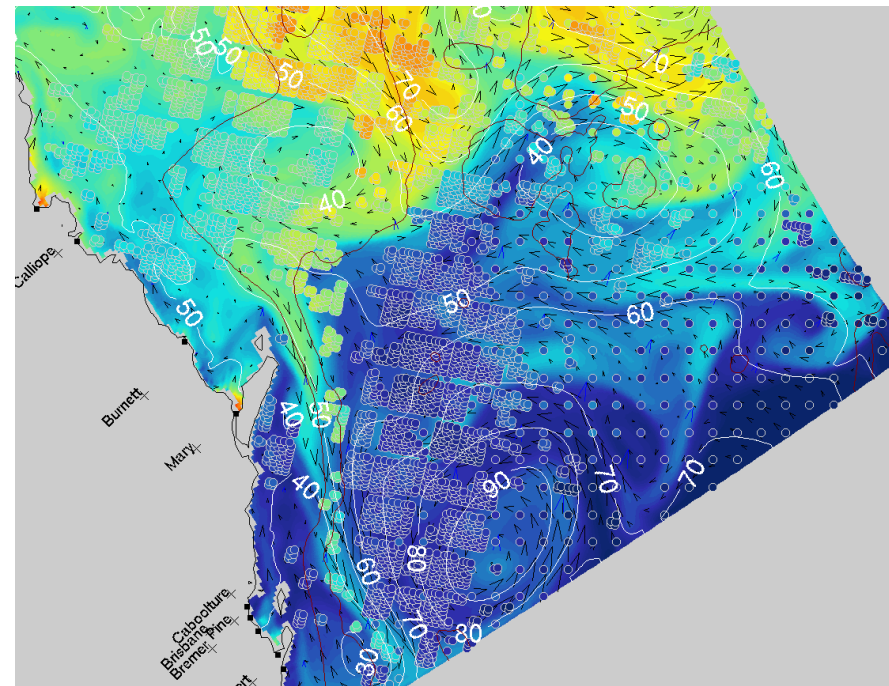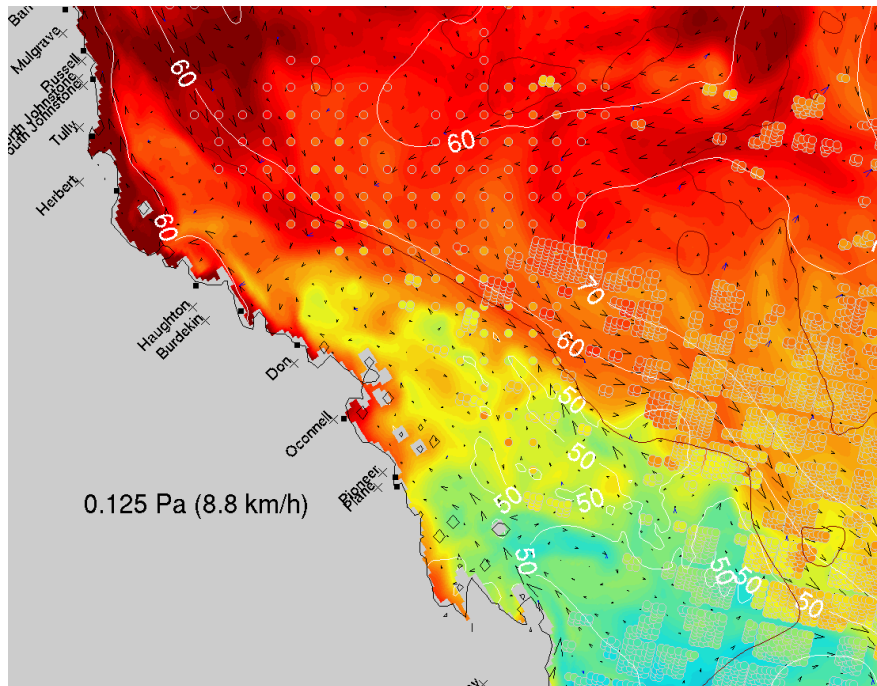
Monthly mean sea surface temperature

Variable (units)	Forecast MAD	Forecast Bias
SLA (cm)	5.87	-0.07
SST (K)	0.346	-0.0551
T (K)	0.535	0.142
S (psu)	0.102	-0.015

Hindcast MAD	Hindcast Bias	Observations*
8.36	0.2	1409569
0.54	-0.238	33302676
0.78	0.202	94912
0.133	-0.032	93177
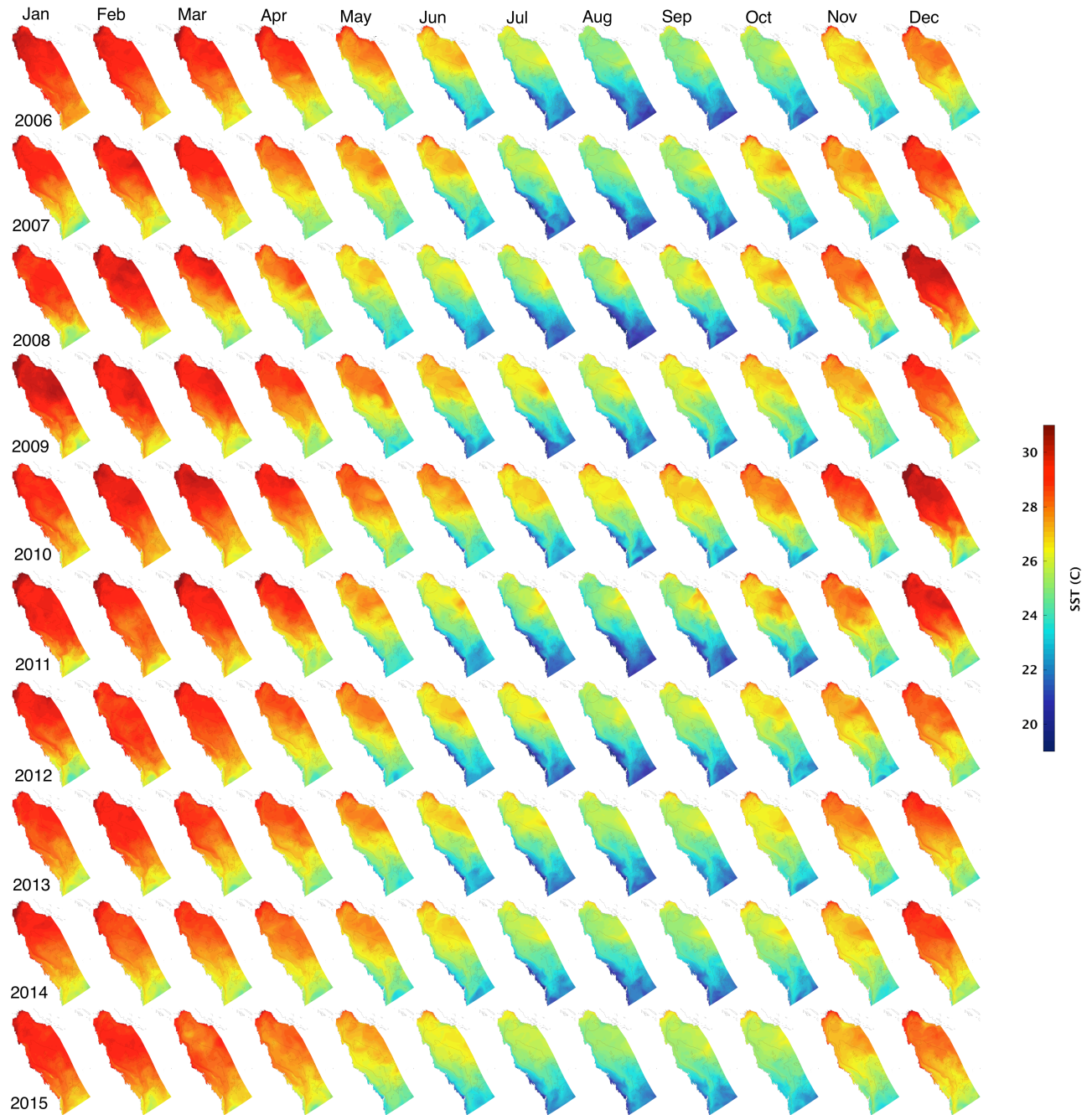
Climatological monthly mean SST anomalies

Variable (units)	Forecast MAD	Forecast Bias
SLA (cm)	5.87	-0.07
SST (K)	0.346	-0.0551
T (K)	0.535	0.142
S (psu)	0.102	-0.015

Hindcast MAD	Hindcast Bias	Observations⋆
8.36	0.2	1409569
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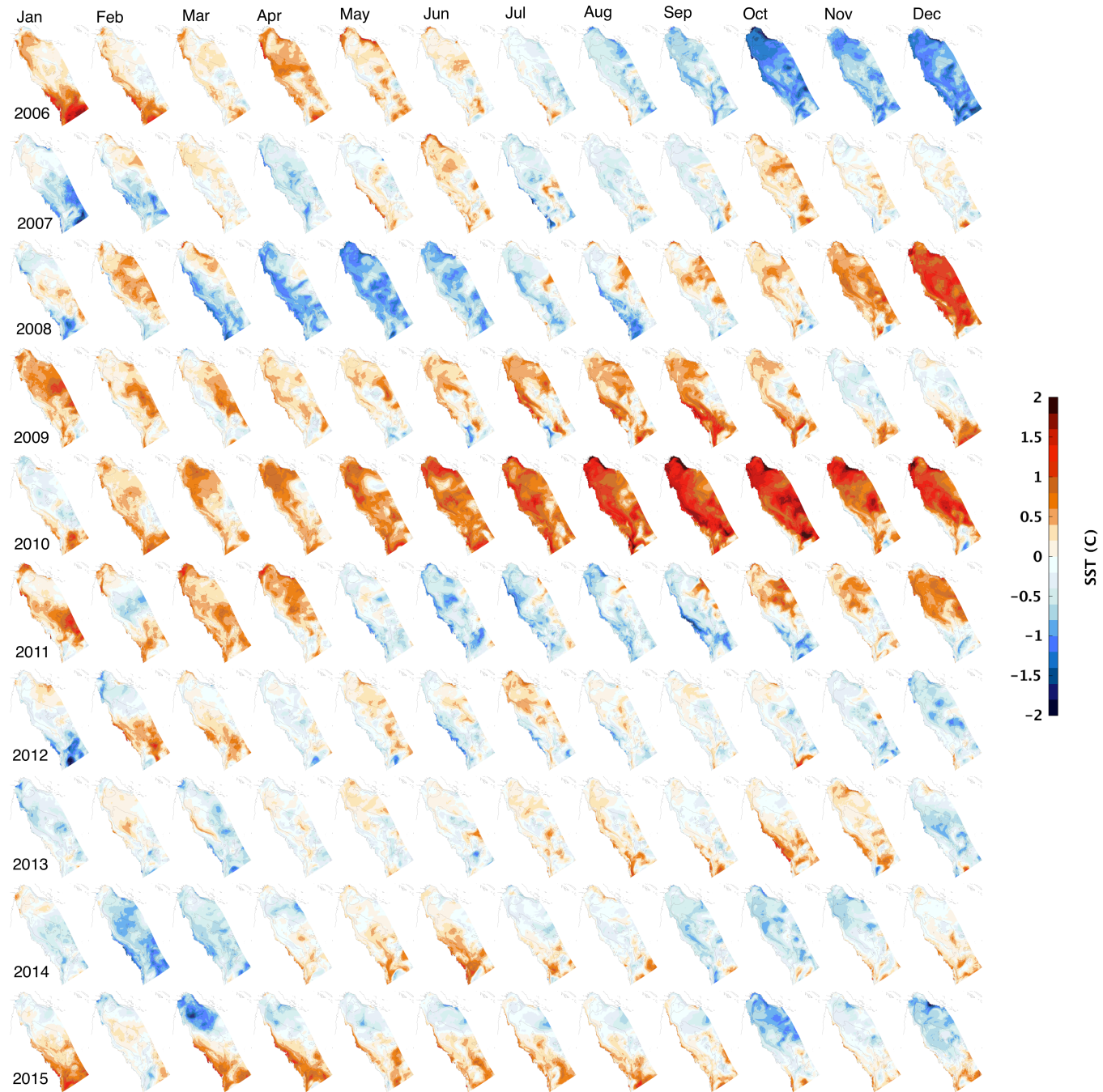
Climatological monthly mean SSS anomalies

Variable (units)	Forecast MAD	Forecast Bias
SLA (cm)	5.87	-0.07
SST (K)	0.346	-0.0551
T (K)	0.535	0.142
S (psu)	0.102	-0.015

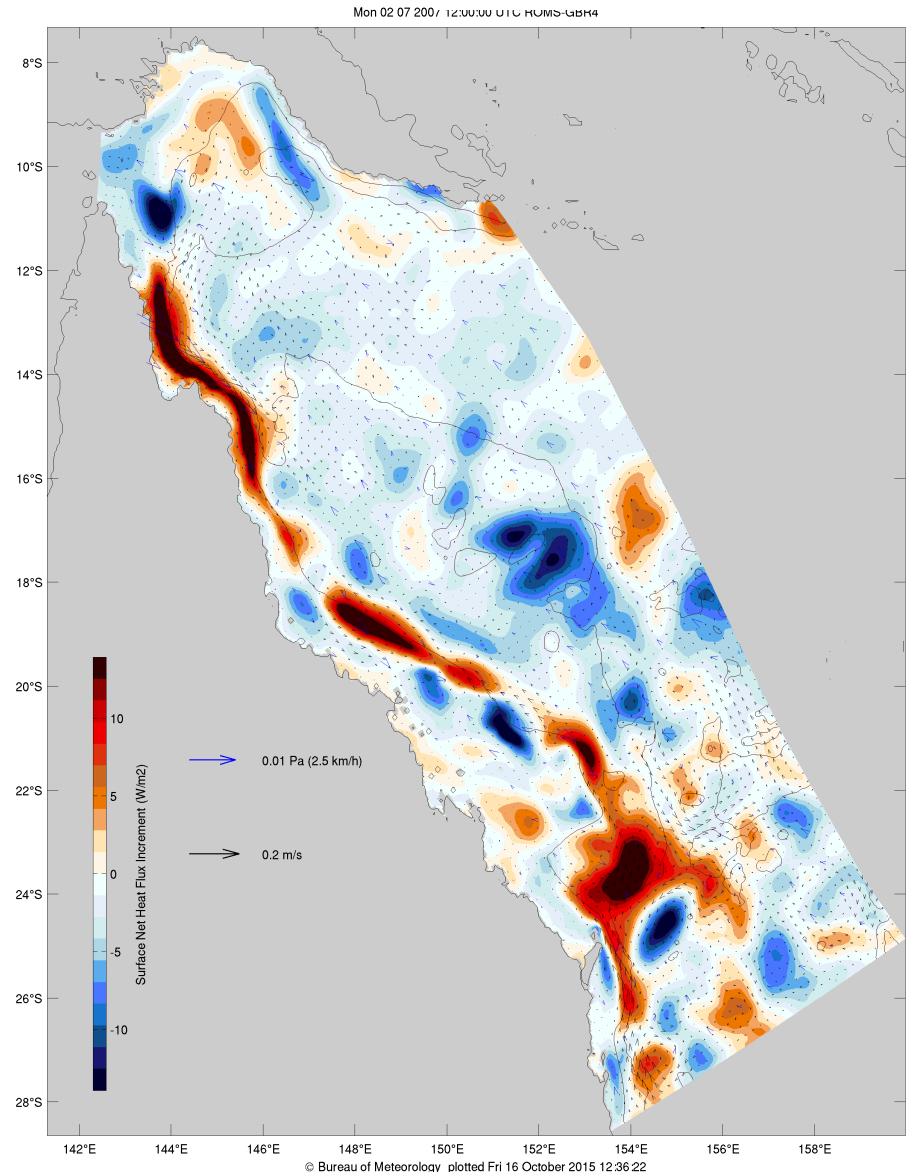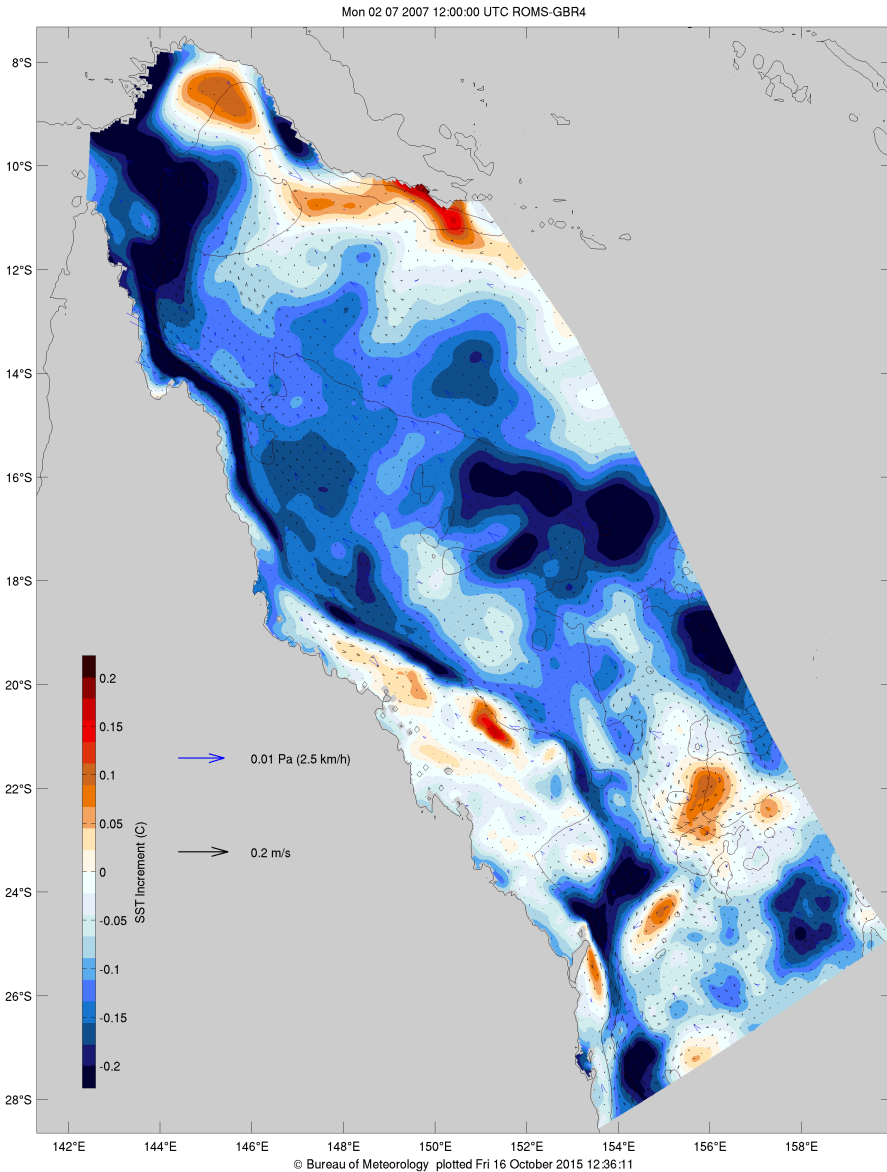| Hindcast MAD	Hindcast Bias	Observations*
8.36	0.2	1409569
0.54	-0.238	33302676
0.78	0.202	94912
0.133	-0.032	93177
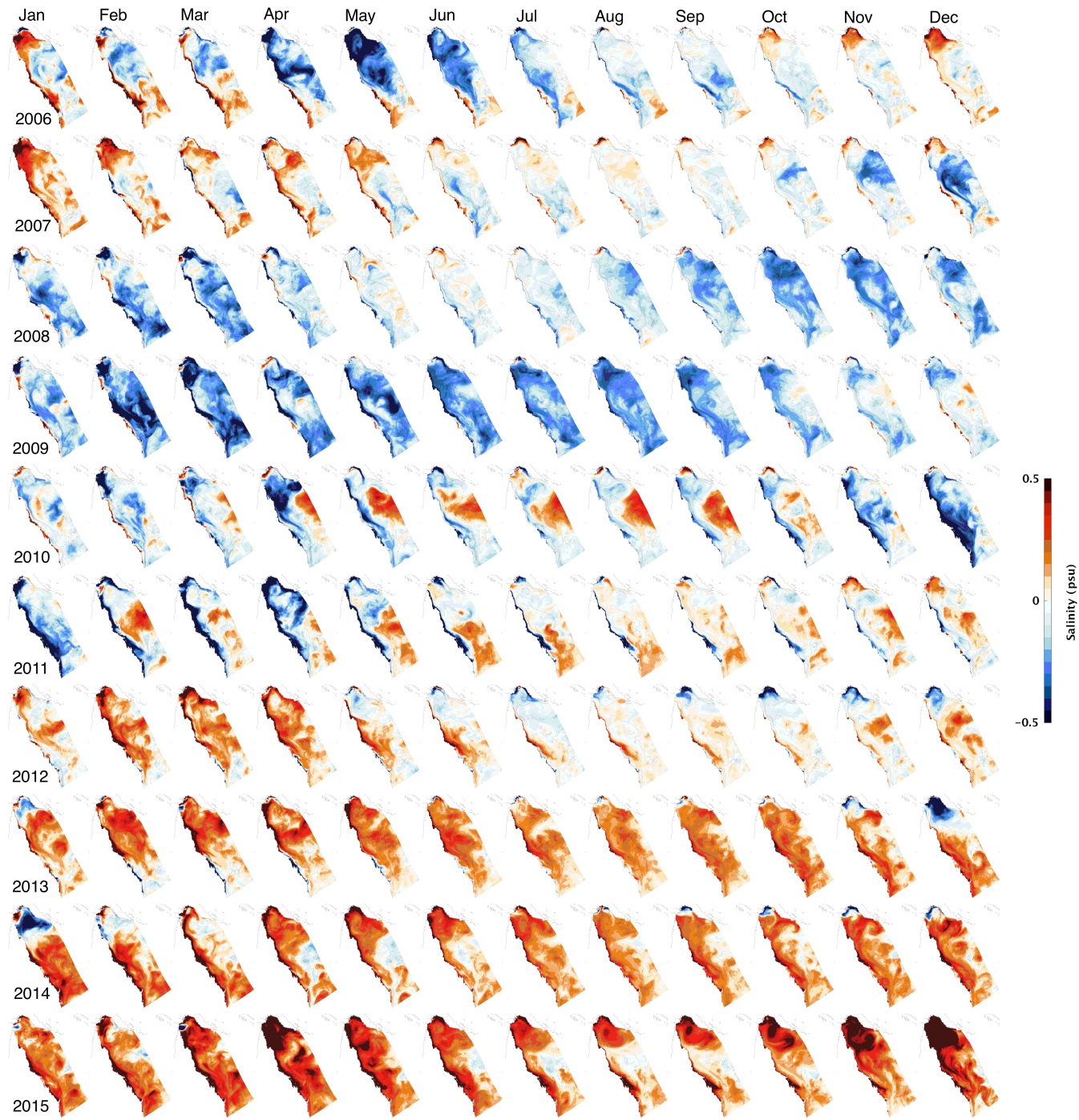
Correlation between climatological monthly mean SST and bottom temperatures
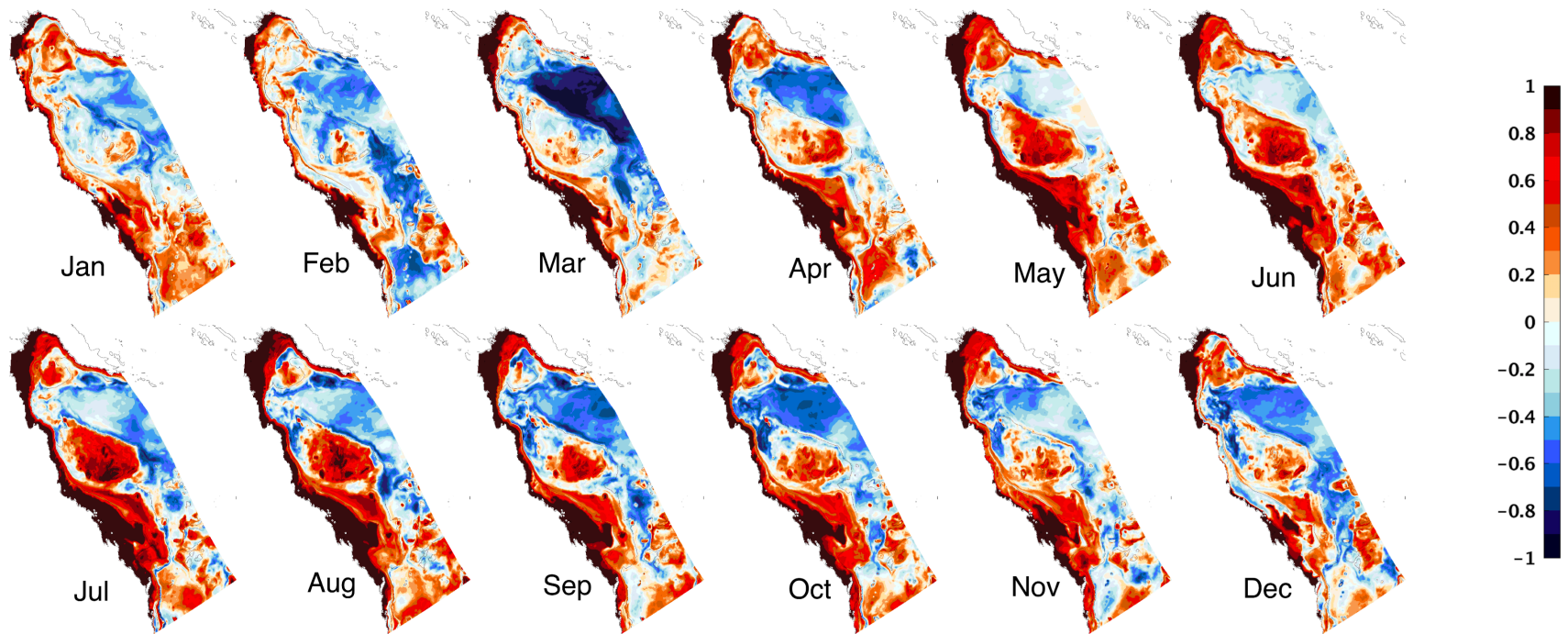
Reanalysis mean increments without AVHRR bias correction

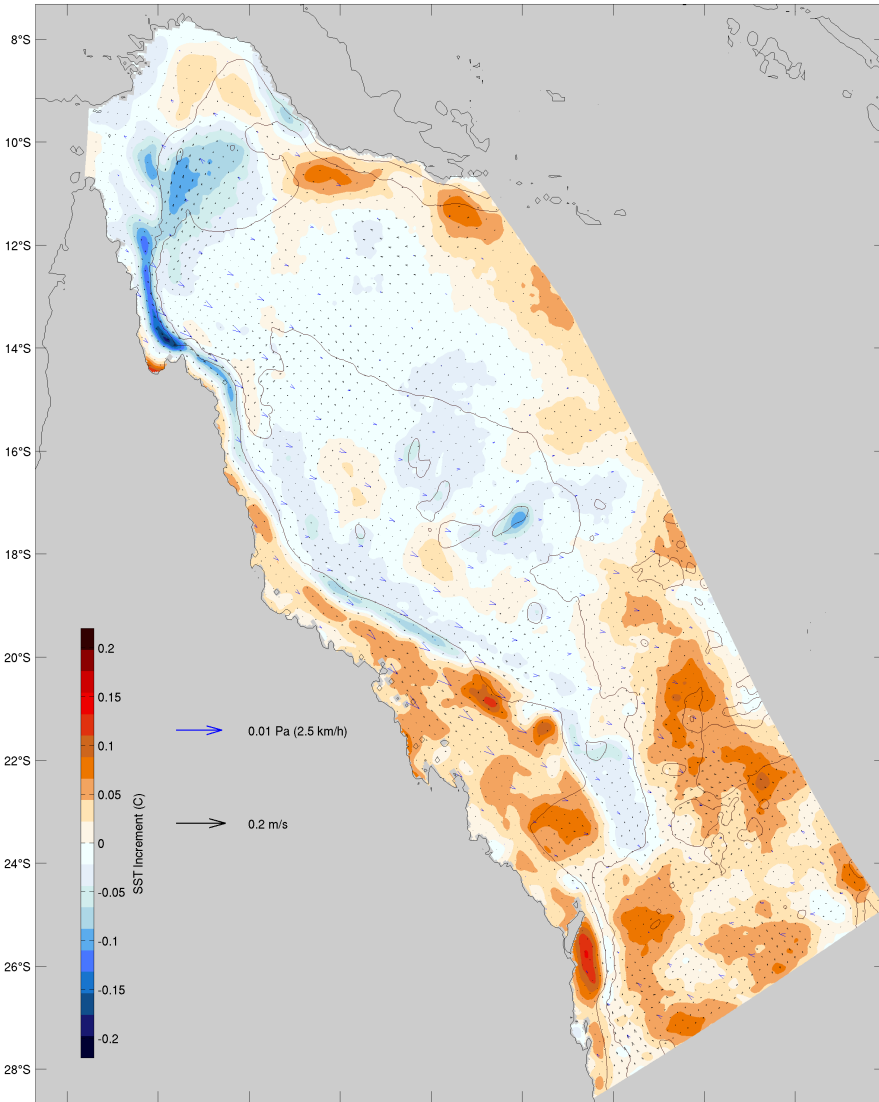$$\mathbf{K}\left[\mathbf{y} - \mathcal{H}(\overline{\mathbf{x}}^f)\right]$$

NAVO-AVHRR GHRSST SST bias correction estimated by comparing retrievals with drifting buoys

Reanalysis mean increments without AVHRR bias correction

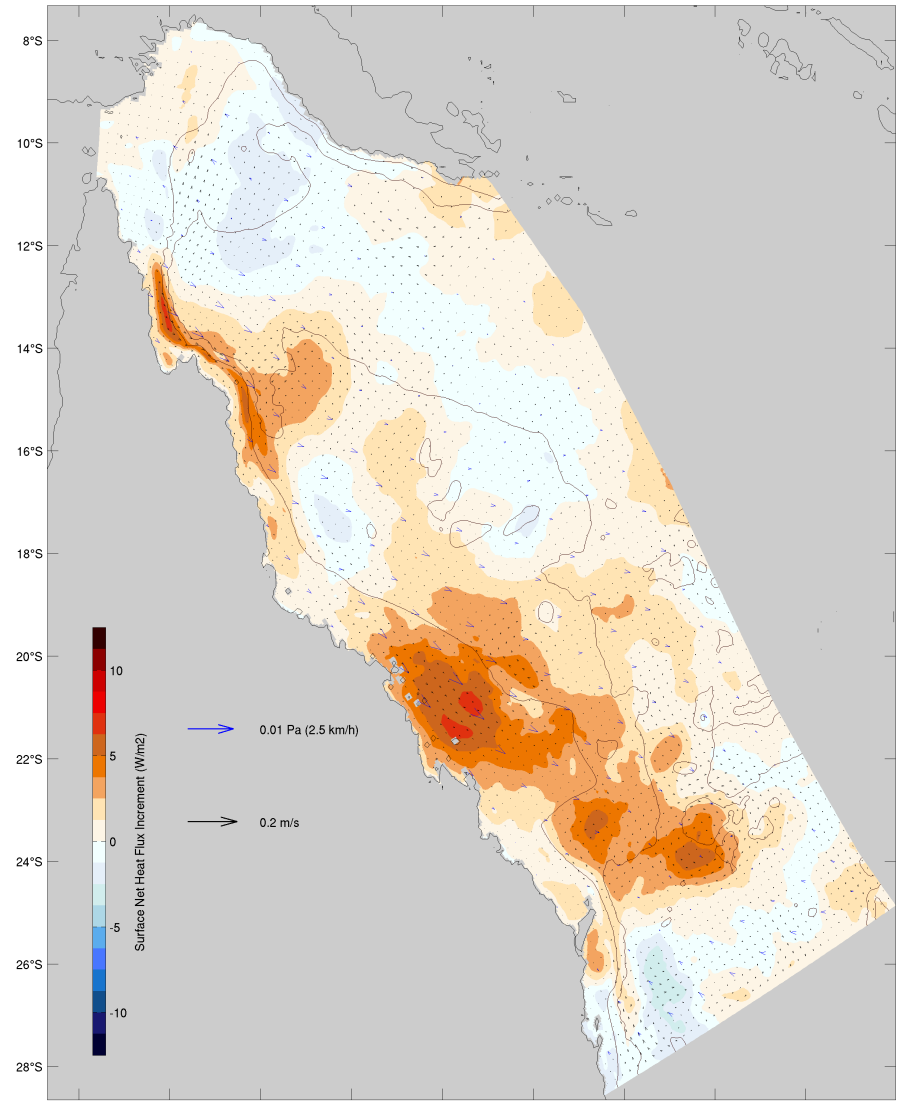$$\mathbf{K}\left[\mathbf{y} - \mathcal{H}(\overline{\mathbf{x}}^f)\right]$$

NAVO-AVHRR GHRSST SST bias correction estimated by comparing retrievals with drifting buoys

eSAMarine - nowcast-forecast system for South Australia (SARDI/BoM project)

eSAMarine - nowcast-forecast system for South Australia

Wed 19 10 2016 03:00:00 UTC eSAMarine

Valid time Wed 19 10 2016 03:00:00 UTC
max 18.44
min 11.65
mad SST NaN
bias SST NaN
obs# SST super 0
obs# SST raw 0
mad SLA NaN cm
bias SLA NaN cm
obs# SLA super 0
obs# SLA raw 0
max current 0.91 m/s
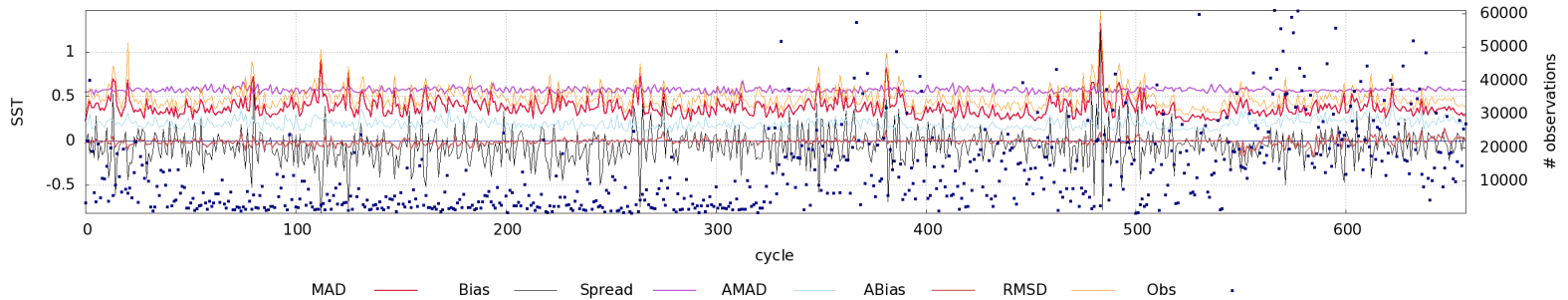avg current 0.19 m/s
max wind 18.84 kns
avg wind 11.85 kns
Plotted Wed 19 October 2016 06:48:21 EST
© Bureau of Meteorology – Research Product

Wed 19 10 2016 03:00:00 UTC eSAMarine

Valid time Wed 19 10 2016 03:00:00 UTC
max 0.54
min -3.25
mad SST NaN
bias SST NaN
obs# SST super 0
obs# SST raw 0
mad SLA NaN cm
bias SLA NaN cm
obs# SLA super 0
obs# SLA raw 0
max current 0.91 m/s
avg current 0.19 m/s
max wind 18.84 kns
avg wind 11.85 kns
Plotted Wed 19 October 2016 07:04:37 EST
© Bureau of Meteorology – Research Product

eReefs - nowcast-forecast system for GBR

Wed 19 10 2016 03:00:00 UTC eReefs

Wed 19 10 2016 03:00:00 UTC
max 30.46
min 20.81
mad SST NaN
bias SST NaN
obs# SST super 0
obs# SST raw 0
mad SLA NaN cm
bias SLA NaN cm
obs# SLA super 0
obs# SLA raw 0
max U 2.26 m/s
avg U 0.31 m/s
max wind 21.69 kns
avg wind 11.87 kns
Plotted Wed 19 October 2016 08:32:44 EST
© Bureau of Meteorology – Research Product

Wed 19 10 2016 03:00:00 UTC eReefs

Wed 19 10 2016 03:00:00 UTC
max 3.72
min −0.96
mad SST NaN
bias SST NaN
obs# SST super 0
obs# SST raw 0
mad SLA NaN cm
bias SLA NaN cm
obs# SLA super 0
obs# SLA raw 0
max U 2.26 m/s
avg U 0.31 m/s
max wind 21.69 kns
avg wind 11.87 kns
Plotted Wed 19 October 2016 08:46:01 EST
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Thank you…

Paul Sandery
paul.sandery@bom.gov.au