ARC-linkage

What is the Bureau of Meteorology looking for…

- Delivery of a MOM5(1/10) and MOM6(1/10 + 1/30?) on year 2 and year 4 respectively
  - Validated, minimising systematic bias
  - Pathway to potential ocean forecast upgrades
- Provide a pathway for the introduction of sea-ice into the ocean forecasts
  - Full global ocean sea-ice forecasting
  - Pathway to sea-ice forecasting
- Provide the infrastructure for exchange variables between MOMx and WWIII

COSIMA

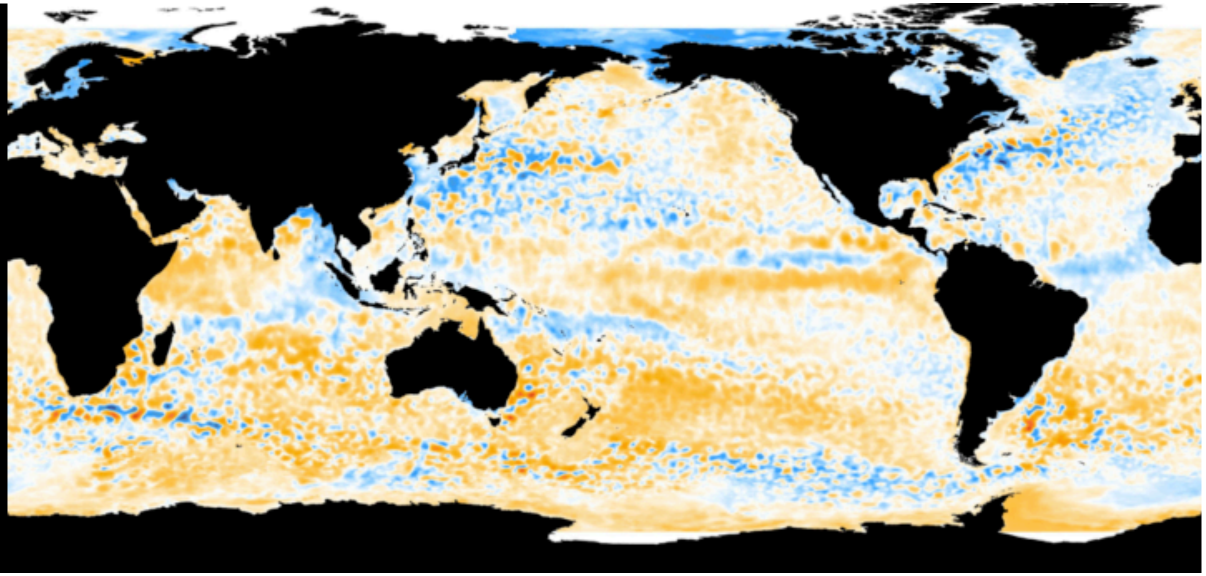
What is the Bureau of Meteorology looking for…

- Network/forum for all global ocean sea-ice modelling expertise (Forecasting through Climate)
  - Primary motivation has been to build community support for sea-ice modelling
- Scope includes all Bureau ocean models (MOMx, NEMO, CICE)
  - Bureau responsibility but community acceptance and engagement
- Provide a current report card of community ocean and sea-ice models
  - Pros/cons of available models against common metrics
  - Engage in global community evaluation frameworks
  - Southern hemisphere tuned
- Linkage with coastal community (global models need to be credible for nesting/downscaling)
  - 1/10 => 1/30 pushing into shelf resolving (5 year time frame for ocean forecasting)
  - Explicit tides

Bureau ocean forecasting targets

- OceanMAPSv3.1 – 2017
  - MOM5(1/10)
- Research projects
  - CICE data assimilation research project (MSA)
- OceanMAPSv4 – 2018/19
  - MOM5(1/10) + CICE (full global domain)
  - Options (Explicit tides, Ensemble (small), Bulk or Weakly coupled atmosphere)
- Research projects (2018-2020)
  - Coupled modelling MOM5/6-WWIII-CICE (unfunded/UniMelb collab?)
  - Coupled data assimilation MOM5/6-WWIII (MSA)
- OceanMAPSv5 – 2020/21
  - MOM6(1/10 + 1/30?) + WWIII + CICE?
  - Coupled ocean-wave-sea-ice DA
  - Options (Explicit tides, Ensemble (large), Bulk/Weakly coupled atmosphere)

OceanMAPS version 3.0



Ocean Model
MOM 4p1, Griffies et al., 2008
z* vertical coordinate
Smith and Sandwell, v11.1
3599×1499×50

0-360, 75S-75N (0.1°×0.1°)
0-15 m (Δz = 5 m)
15-90 m (Δz~5 to 10 m)
90-200m (Δz=10 m)
Minimum column depth – 15 m

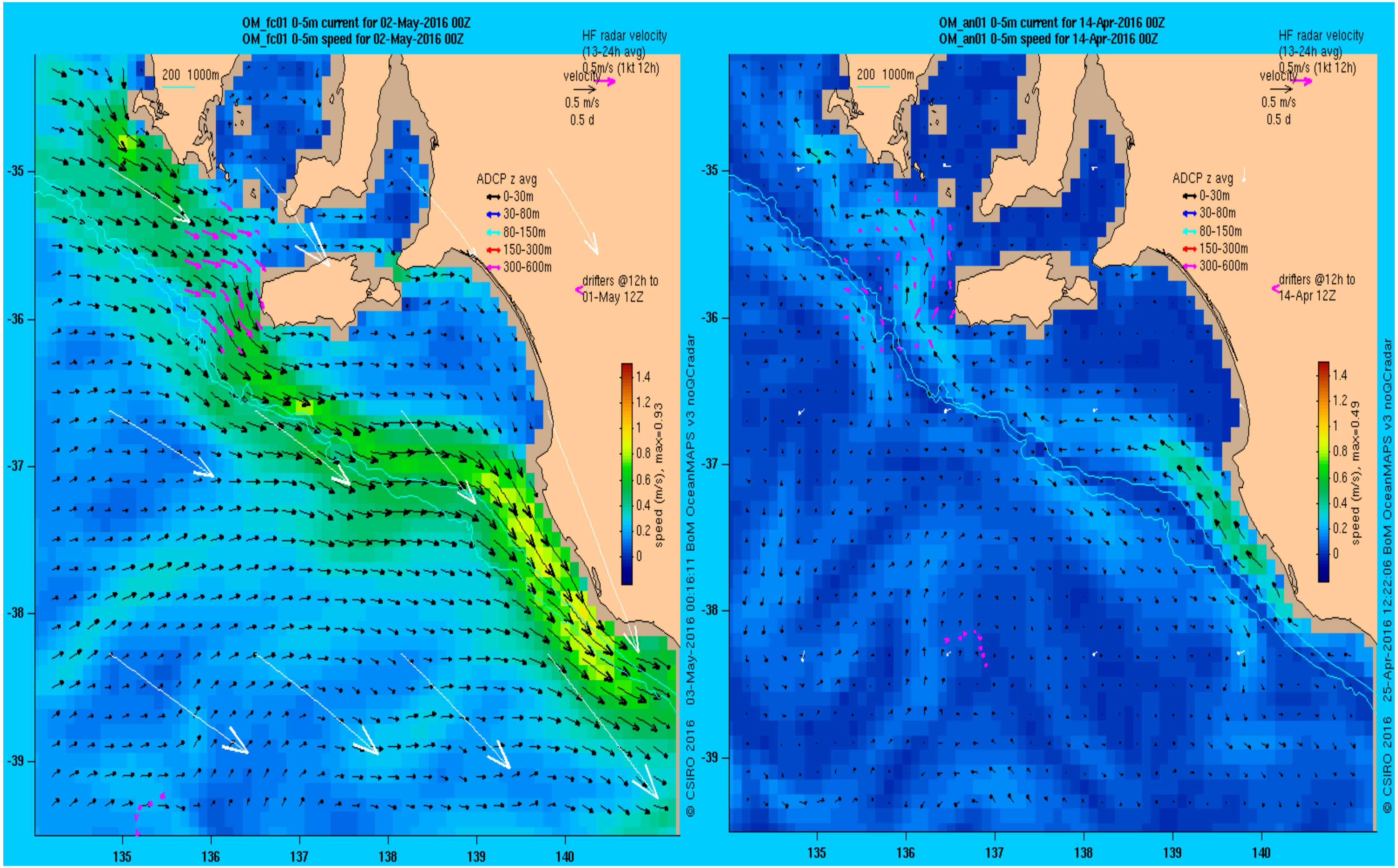
GOTM, K-eps mixed layer scheme
No tides
No sea-ice

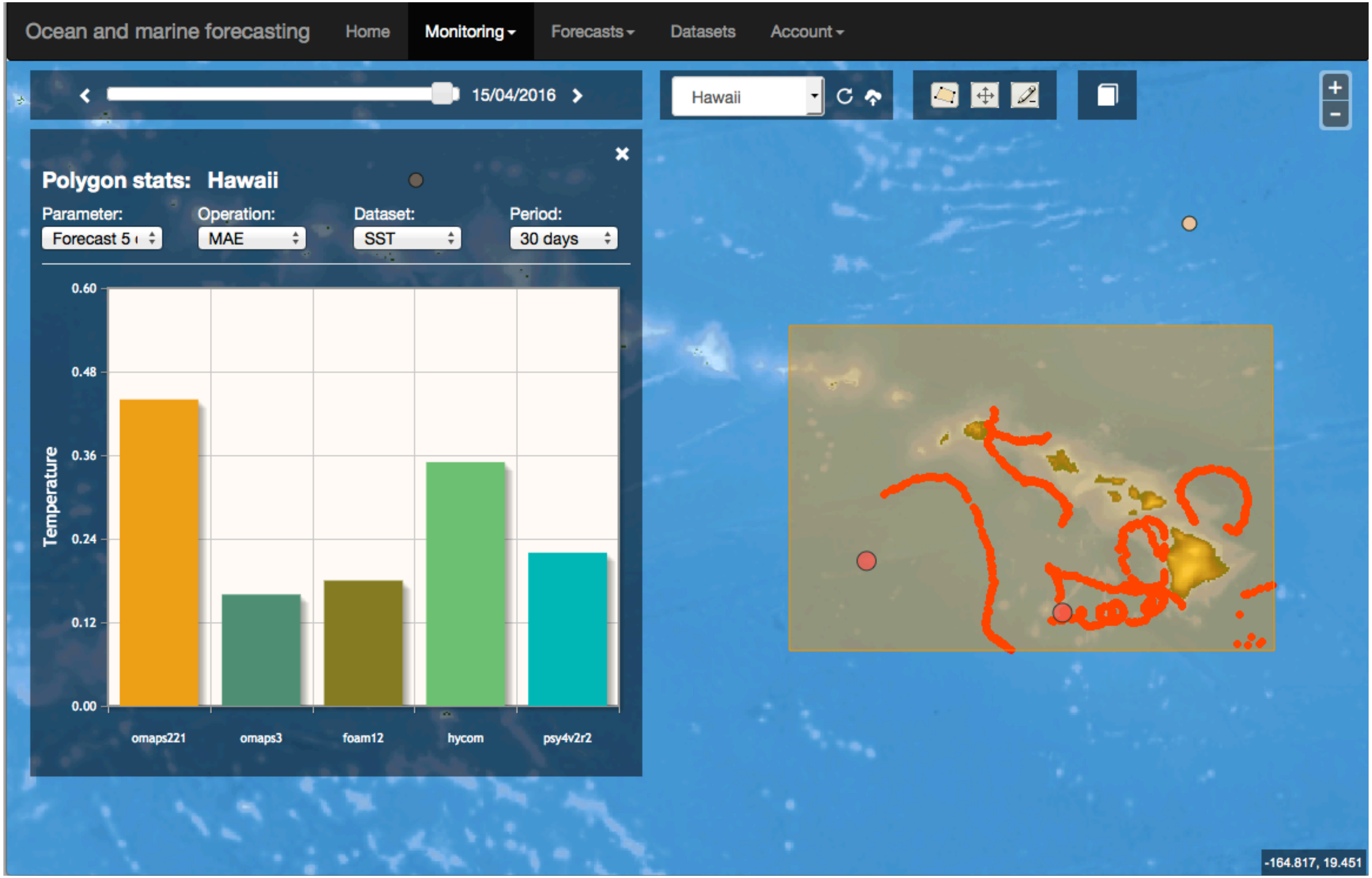
Data Assimilation
ENKF-C (Sakov, 2014)
Ensemble optimal interpolation
State vector (eta, T, S, u, v)
144-member ensemble
Restart initialisation

Observations
Satellite altimetry (Jason2, SARAL, Cryosat2)
Satellite SST (AMSR2, NAVO)
CTD (Argo, GTS), XBT (GTS)

Forcing
ACCESS-G APS1 (fluxes)
Climatological river discharge

http://www.marine.csiro.au/ofam1/om/OM_af01_SAgulfs_sp1/20160502.html





Ocean and marine forecasting
Home
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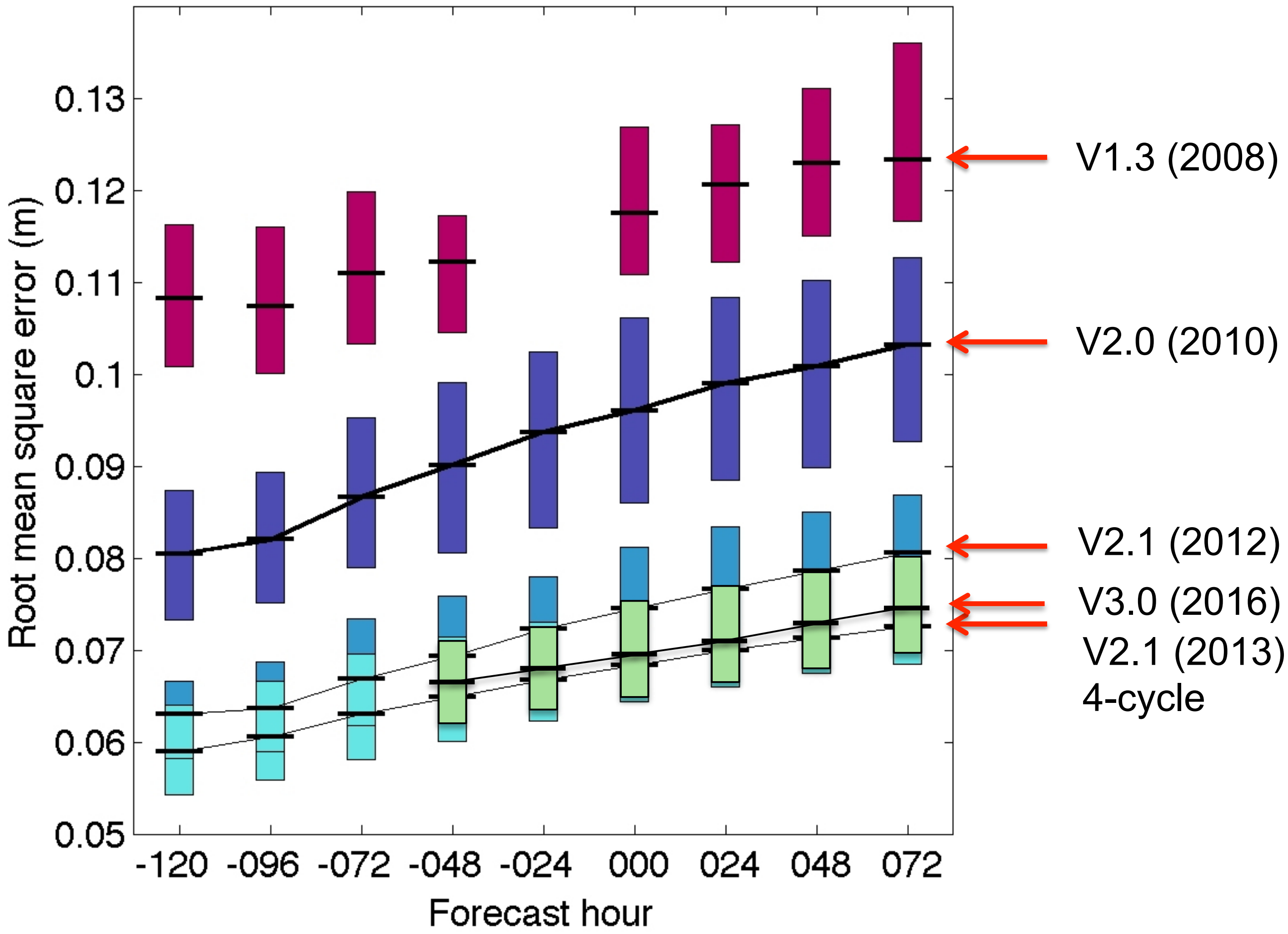
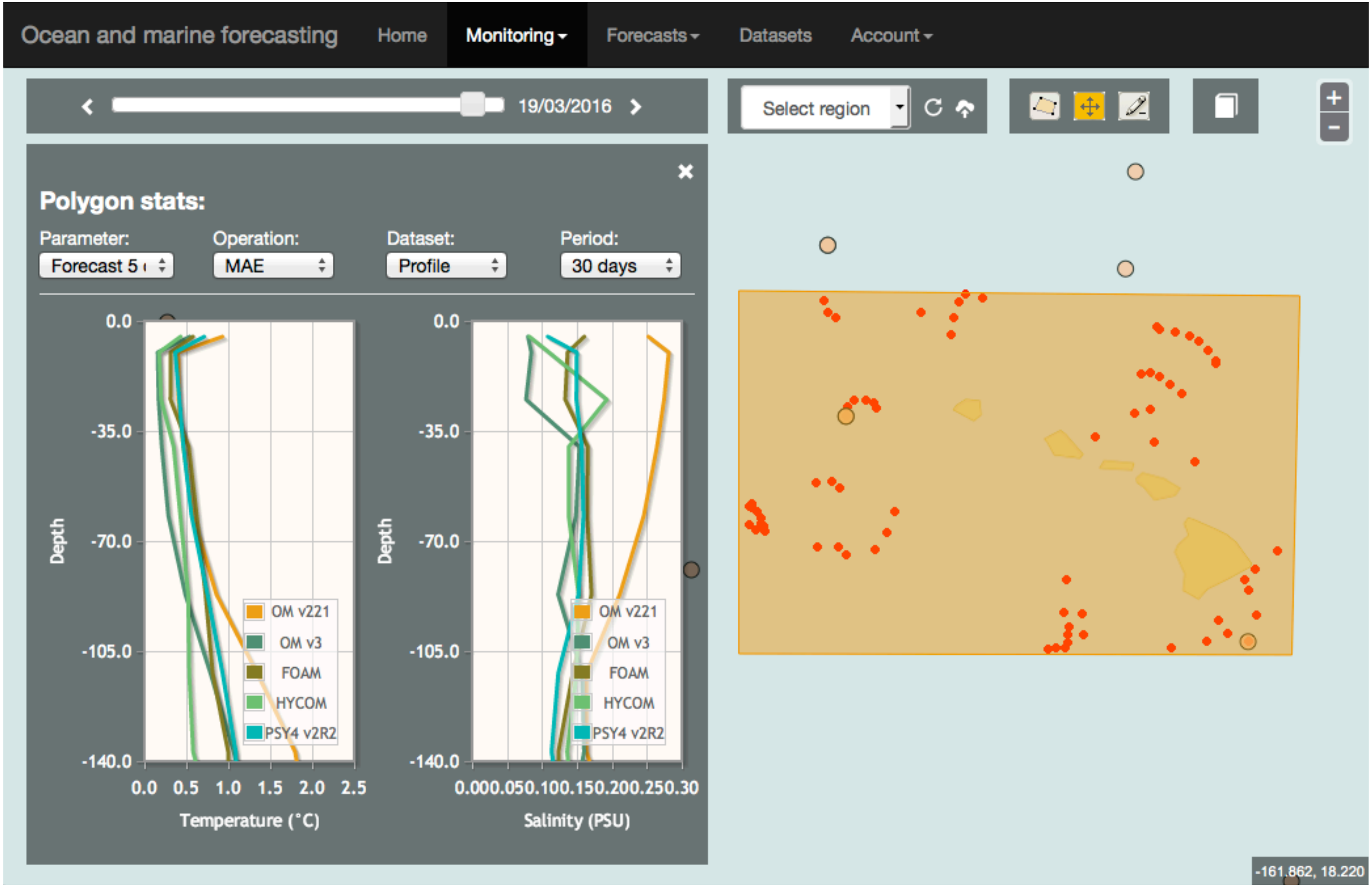
Datasets
Account
15/04/2016
Hawaii
Polygon stats: Hawaii
Parameter:
Forecast 5
Operation:
MAE
Dataset:
SST
Period:
30 days
Temperature
0.60
0.48
0.36
0.24
0.12
0.00
omaps221
omaps3
foam12
hycom
psy4v2r2
-164.817, 19.451

OceanMAPS – forecast error history





Ocean and marine forecasting
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Account
19/03/2016
Select region
Polygon stats:
Parameter:
Forecast 5
Operation:
MAE
Dataset:
Profile
Period:
30 days
0.0
-35.0
-70.0
-105.0
-140.0
Depth
0.0 0.5 1.0 1.5 2.0 2.5
Temperature (°C)
0.000.050.100.150.200.250.30
Salinity (PSU)
OM v221
OM v3
FOAM
HYCOM
PSY4 v2R2
-161.862, 18.220

Model resolution – Why 1/10?

Hurlburt, H.E. (1984). The potential for ocean prediction and the role of altimeter data. Mar. Geod. 8, 17–66
TOPEX Science Working Group, Jet Propulsion Laboratory (US), & Space Administration. Environmental Observation Division. (1981). *Satellite Altimetric Measurements of the Ocean: Report*. Jet Propulsion Laboratory. (only 46 citations)

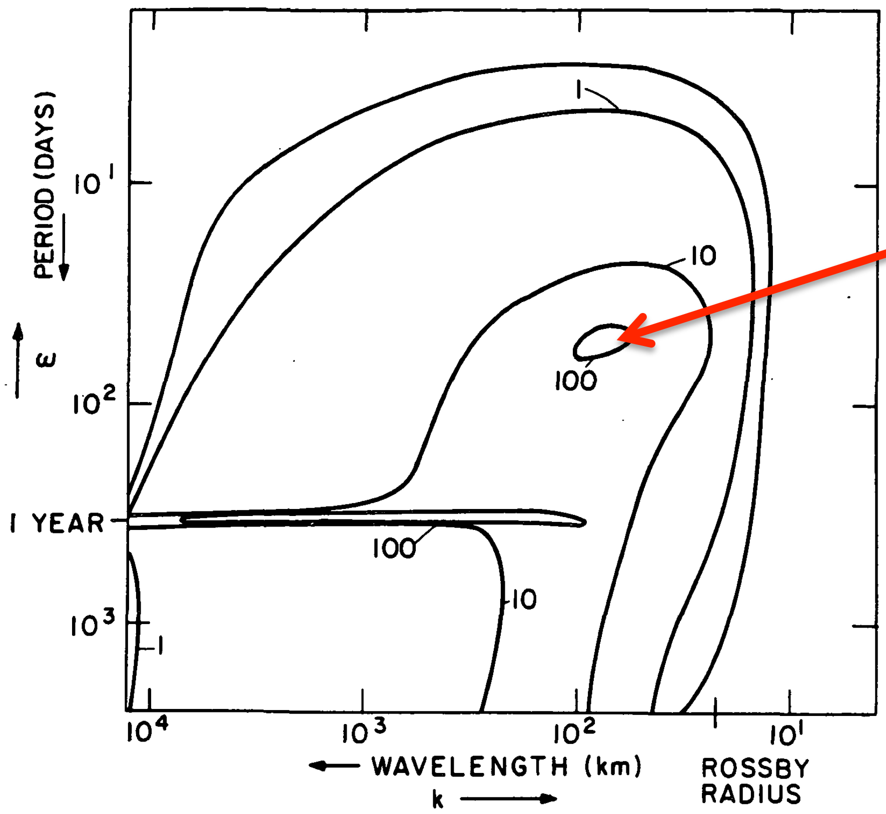


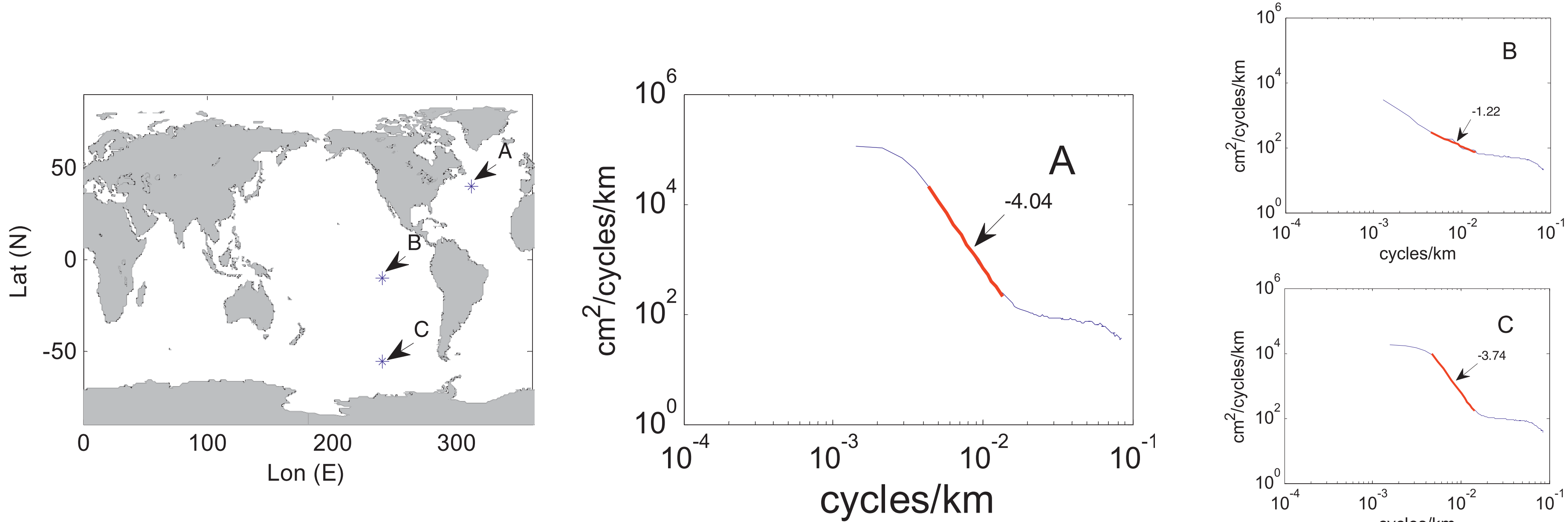
Figure 2.5 Sketch of the frequency-wavenumber spectrum of the general circulation at mid-latitudes, with arbitrary contour units.

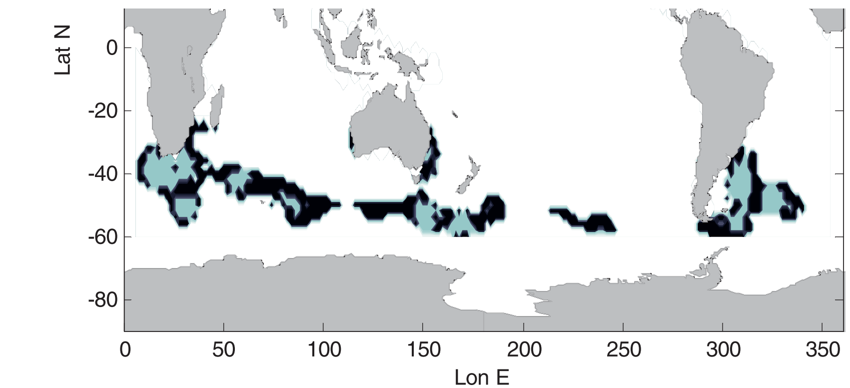
50-100 km
60 days

Requirement
10 km resolution
(>4Δ)

Model resolution - distribution

Xu, Y., & Fu, L. L. (2011). Global variability of the wavenumber spectrum of oceanic mesoscale turbulence. *Journal of physical oceanography*, *41*(4), 802-809.





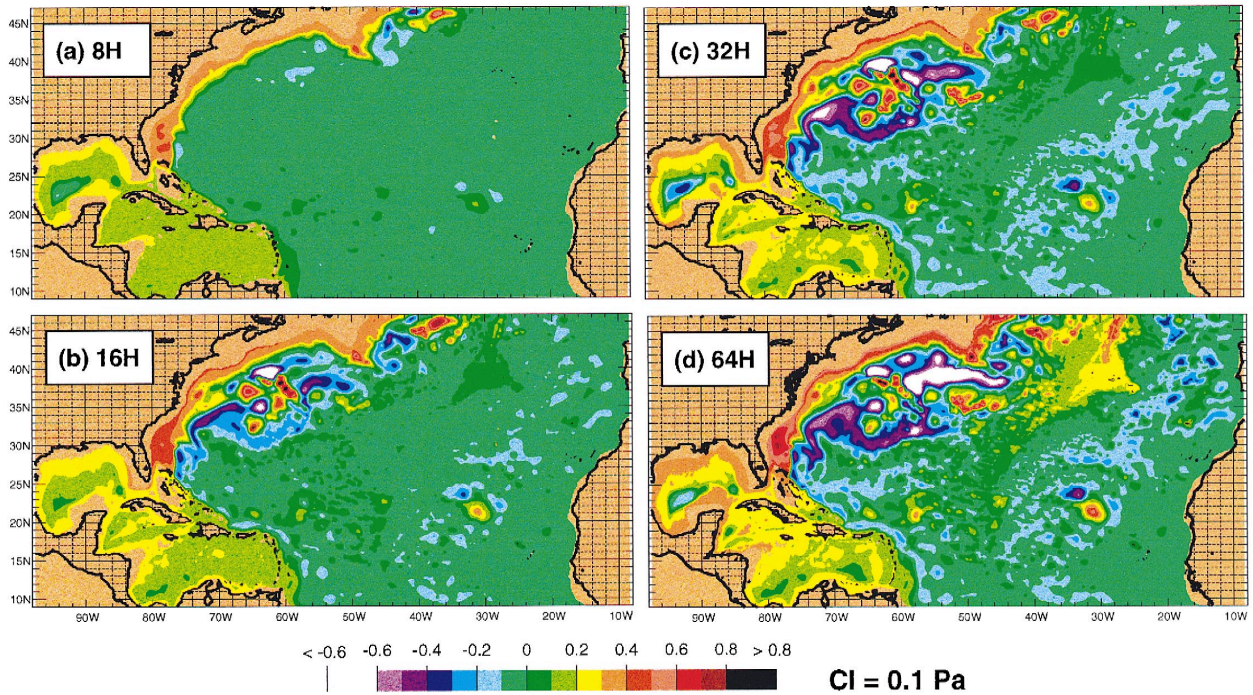
TYPE 1 $k^{-11/3}$ (SQG theory)
TYPE 2 steeper $k^{-11/3}$
TYPE 3 flatter $k^{-11/3}$

FIG. 3. Three types of areas in terms of the spectral power law.

Model resolution – is 1/10 enough?

Hurlbut, H. E., and Hogan, P. J. (2000). Impact of 1/8 to 1/64 resolution on Gulf Stream model–data comparisons in basin-scale subtropical Atlantic Ocean models. *Dynamics of Atmospheres and Oceans*, *32*(3), 283-329.

Hogan, P. J., and Hurlbut, H. E. (2000). Impact of Upper Ocean-Topographical Coupling and Isopycnal Outcropping in Japan/East Sea Models with 1/8° to 1/64° Resolution*. *Journal of Physical Oceanography*, *30*(10), 2535-2561.



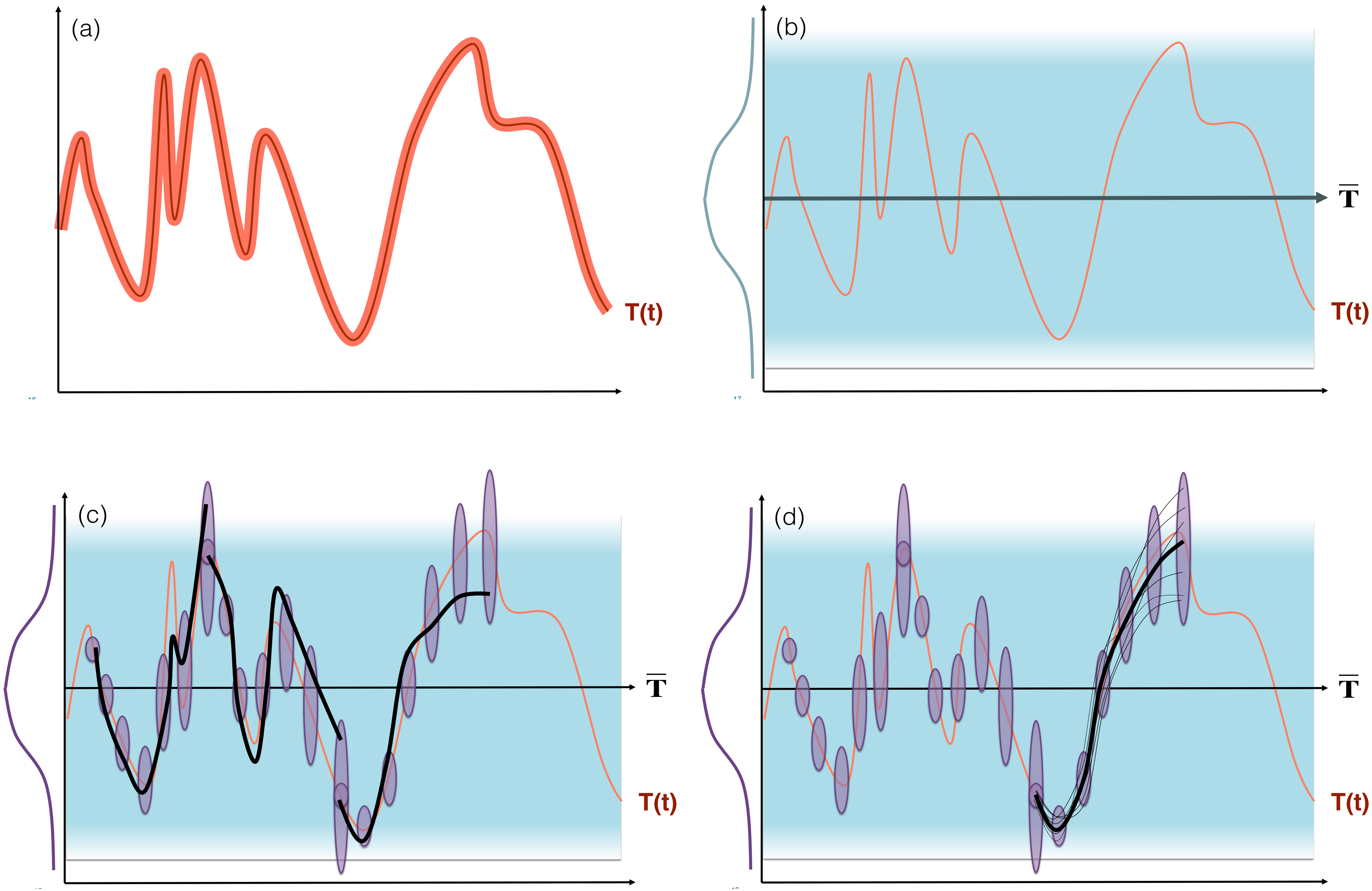
$EKE_{16} >>> EKE_{8}$

$EKE_{32} >> EKE_{16}$

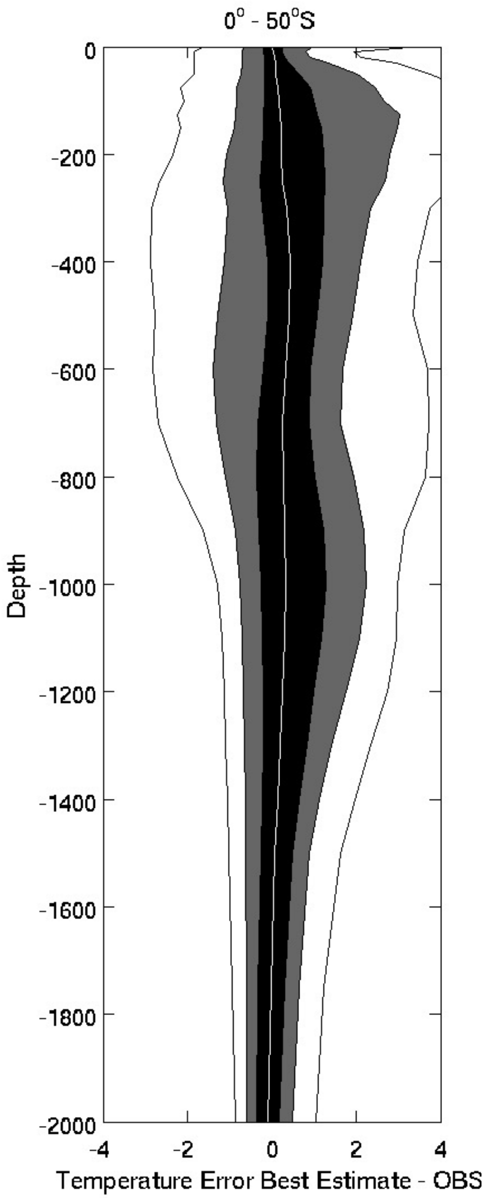
$EKE_{64} > EKE_{32}$

Fig. 10. Whole domain mean abyssal layer pressure deviation (from the rest state) from five-layer Atlantic subtropical gyre experiments with horizontal grid resolution of (a) 1/8° (simulation 8H), (b) 1/16° (simulation 16H), (c) 1/32° (simulation 32H), and (d) 1/64° (simulation 64H). Contour interval of mean density–normalized pressure deviation is 0.1 m^2 s^{-2}. Note the abyssal layer circulation patterns are strongly influenced by the f/h contours of the bottom topography shown in Fig. 1. For example, the NESC is plainly outlined at the three higher resolutions.

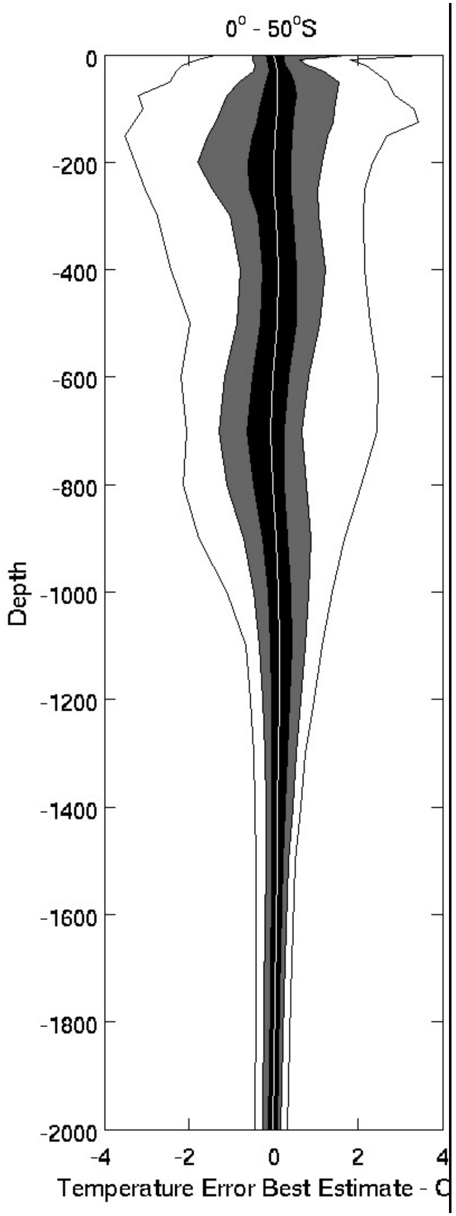
Forecasting – error growth in a chaotic system



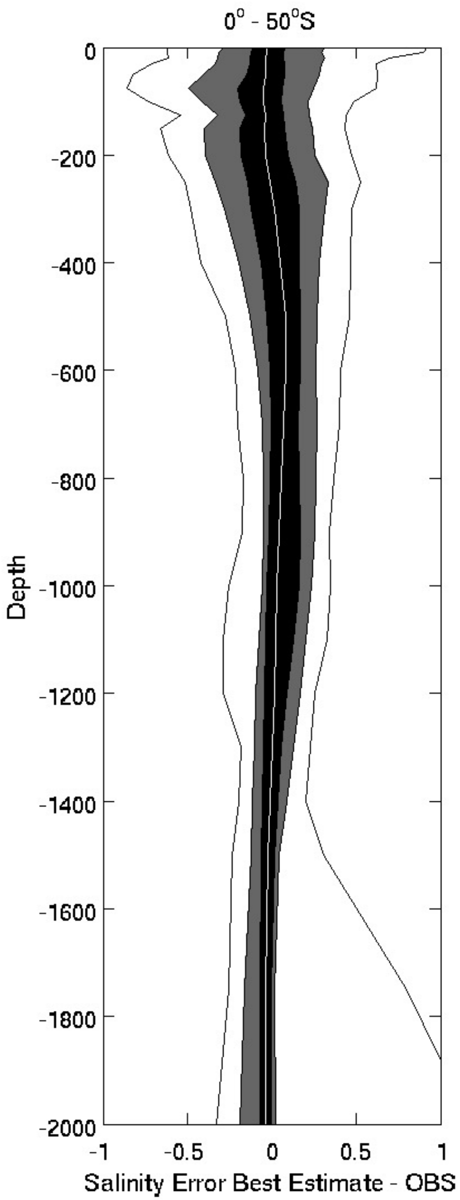
Australian region – Argo profile comparison



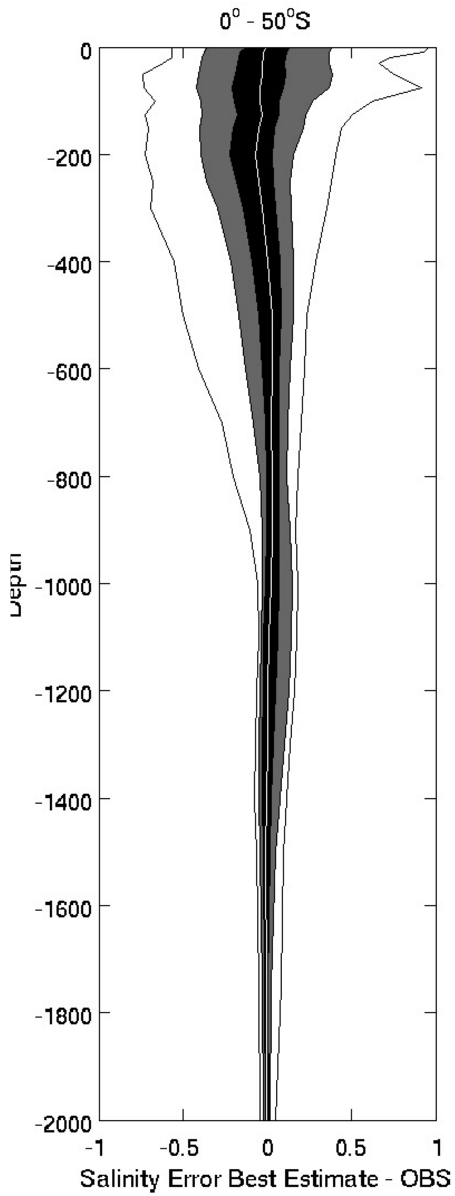
OceanMAPSv2



OceanMAPSv3

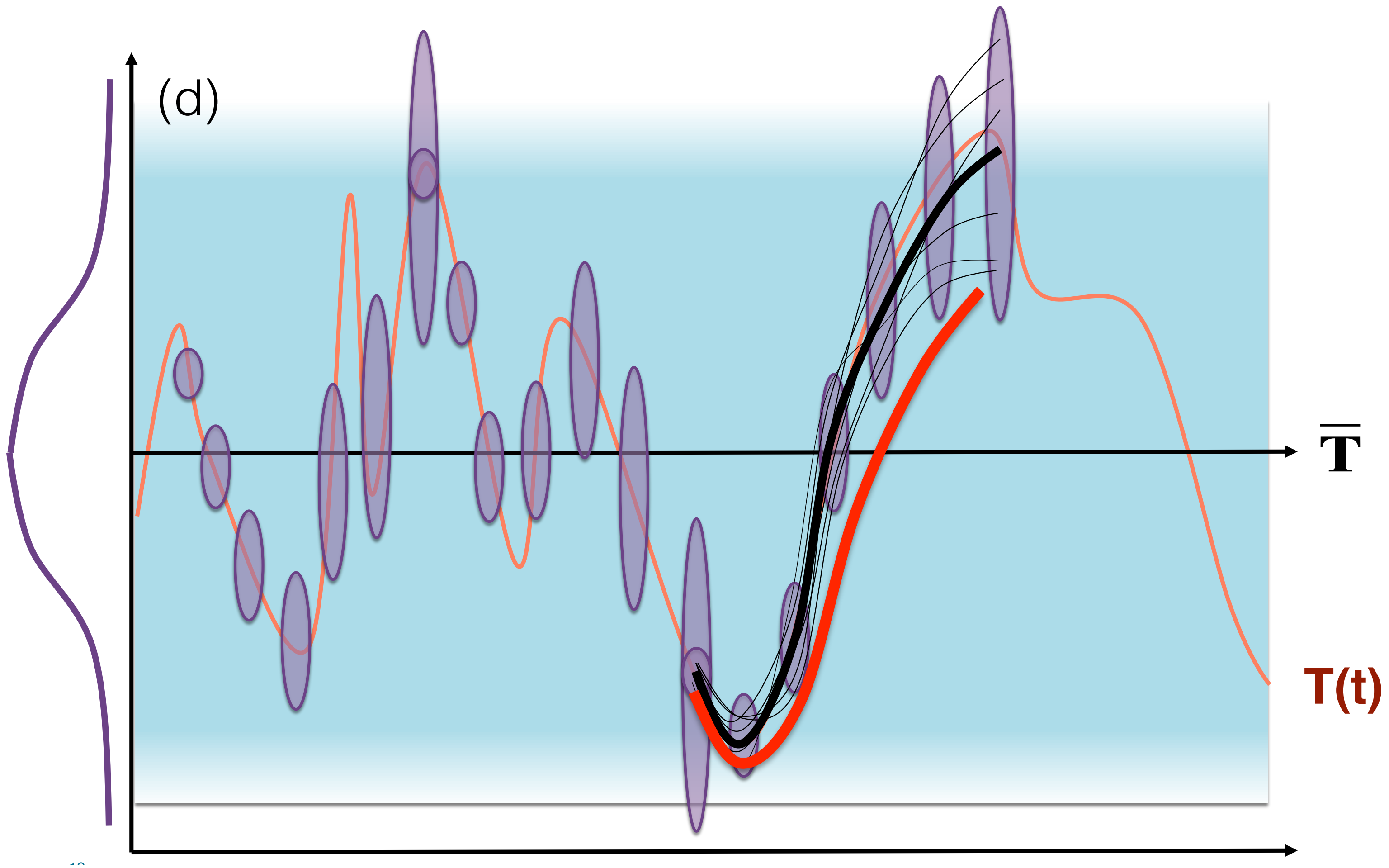


OceanMAPSv2



OceanMAPSv3

Forecasting – what do we need from a model ?



Unbiased
Optimum error growth

Systematic errors

Majority of theory data assimilation and ensemble forecasting likes to assume the model and observations are unbiased. Posterior bias removal is challenging.

Mean error – temporal average

$$E_T\left[T_M - T_O\right] = \frac{1}{N}\sum_{n=1}^{N} T_{M,n}(x_i, y_j, z_k) - T_{O,n}(x_i, y_j, z_k)$$

e.g., mean increment field (time-averaged spatial map)

Posterior calibration

Mean error – spatial average

$$E_X\left[T_M - T_O\right] = \frac{1}{IJK}\sum_{i,j,k=1}^{I,J,K} T^M_{i,j,k}(t_n) - T^O_{i,j,k}(t_n)$$

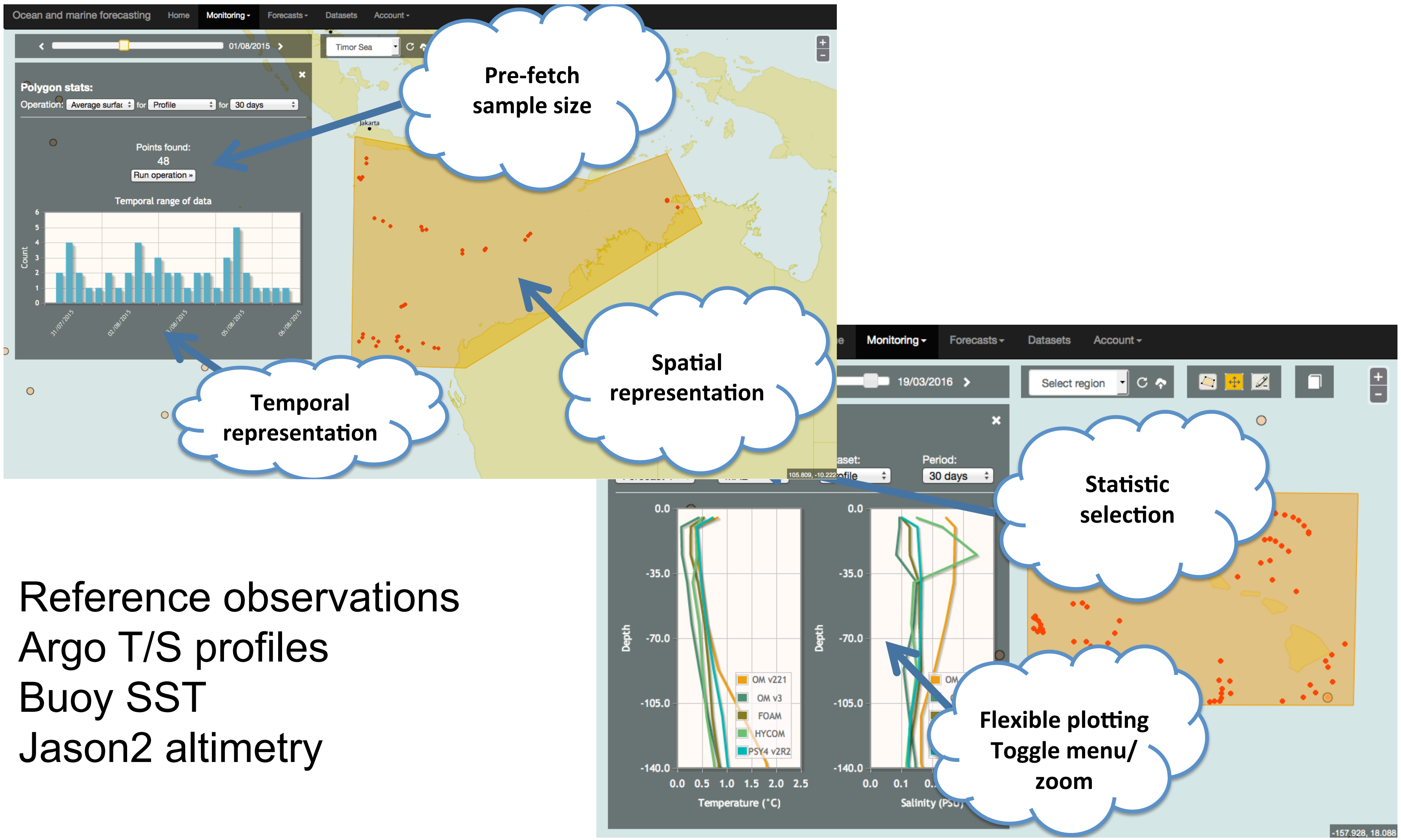
Mean error – conditional (sub-population)

$$E_P\left[T_M - T_O\right] = \frac{1}{P}\sum_{p=1}^{P} T^M_p - T^O_p$$

e.g., **dynamics (storm-surge, upwelling)**, events (search and rescue), **extremes (exceed threshold)**

CLASS4 – forecast verification

Forecast models interpolated to reference observations



Reference observations
Argo T/S profiles
Buoy SST
Jason2 altimetry

Systematic errors – even more model relevant

Mean error – conditional (sub-population)

$$\mathrm{E}_P\left[T_M - T_O\right] = \frac{1}{P}\sum_{p=1}^{P} T_p^M - T_p^O$$

$$T^{n+1} = T^n + F_1 + F_2 + \ldots + F_n$$ Model update

F – advection, mixed layer, geostrophic balance

Example diagnostic populations

F_1 > 90^{th} percentile of F1 distribution

F_1 > % of total F

COSIMA

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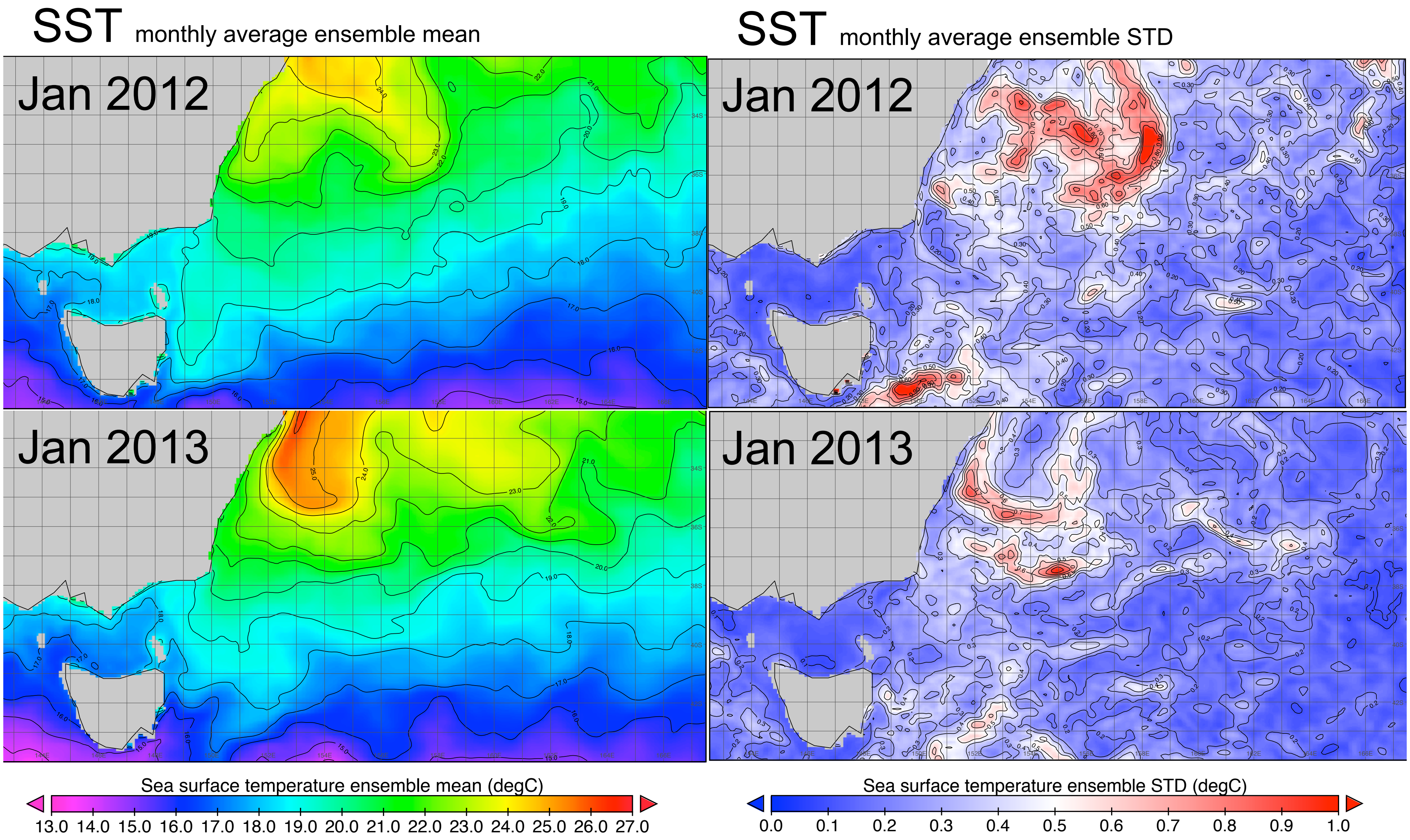
THANK YOU

Predictability – chaotic system and ensembles

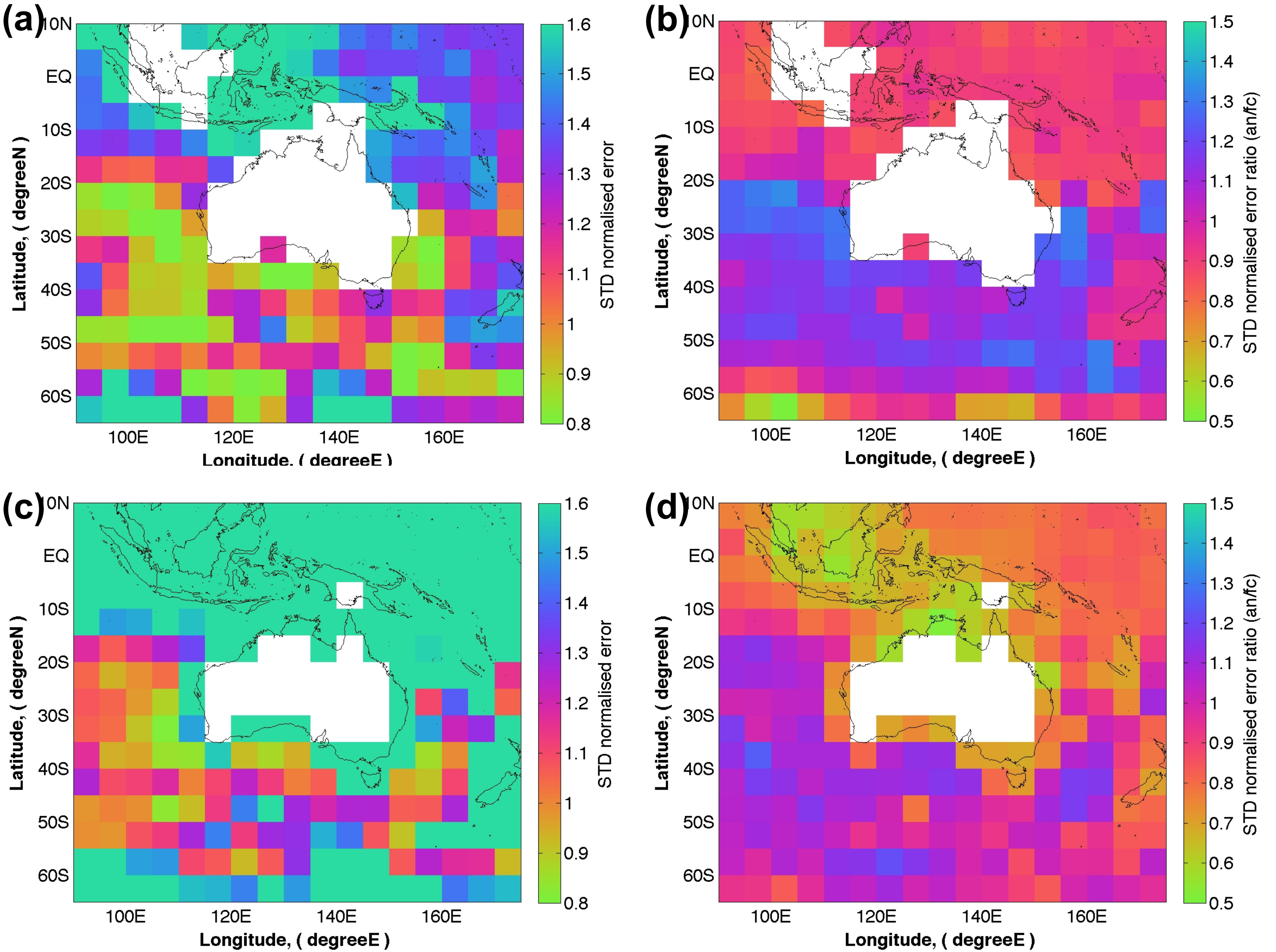


Inference hypothesis testing

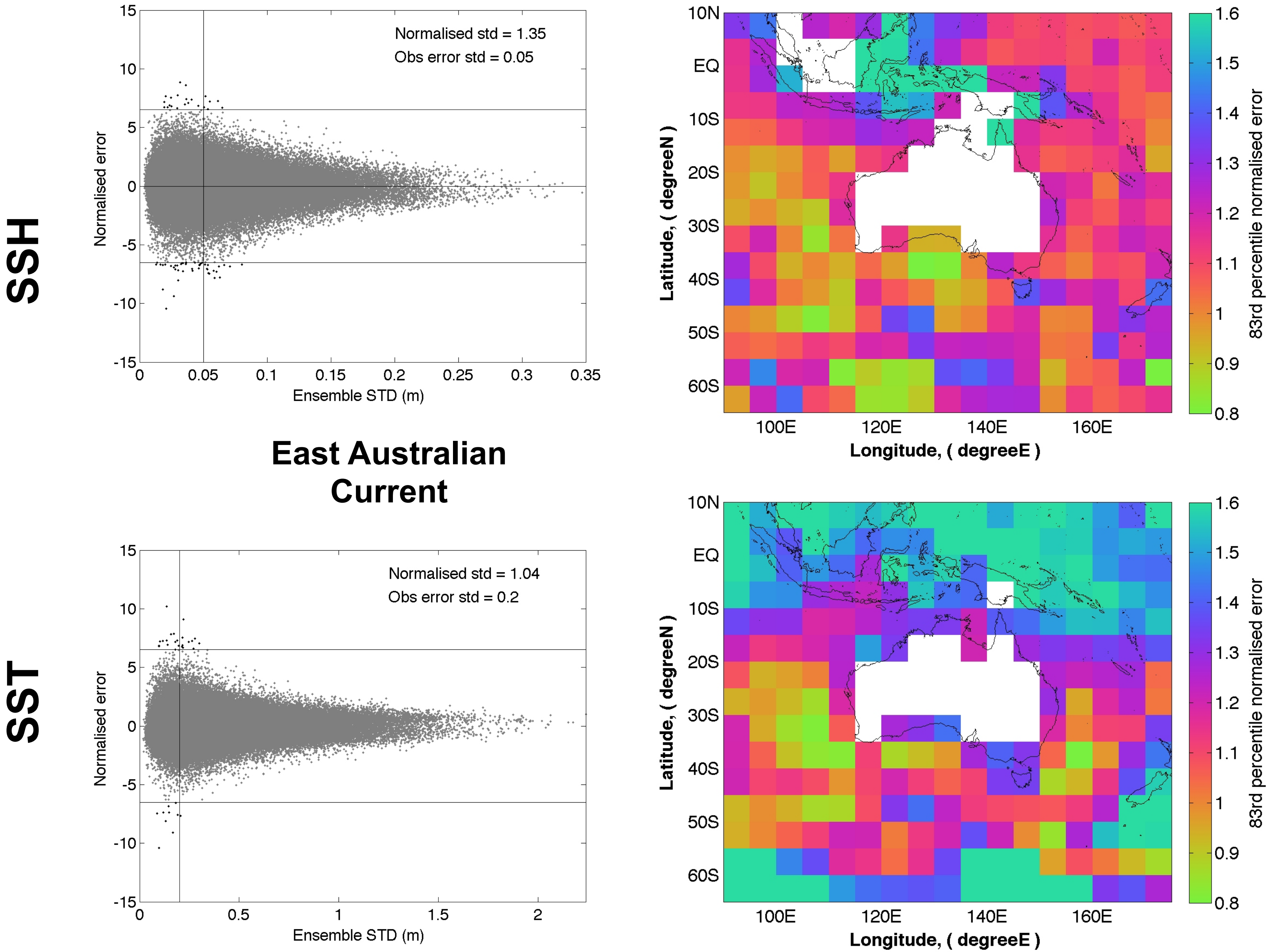
For verification we propose to construct the normalised error distribution as,

$$\varepsilon_Z = \frac{\overline{T}_M - T_O}{\left(\mathrm{var}\left[T_M^c\right] + \sigma_O^2\right)^{1/2}}, \tag{8}$$

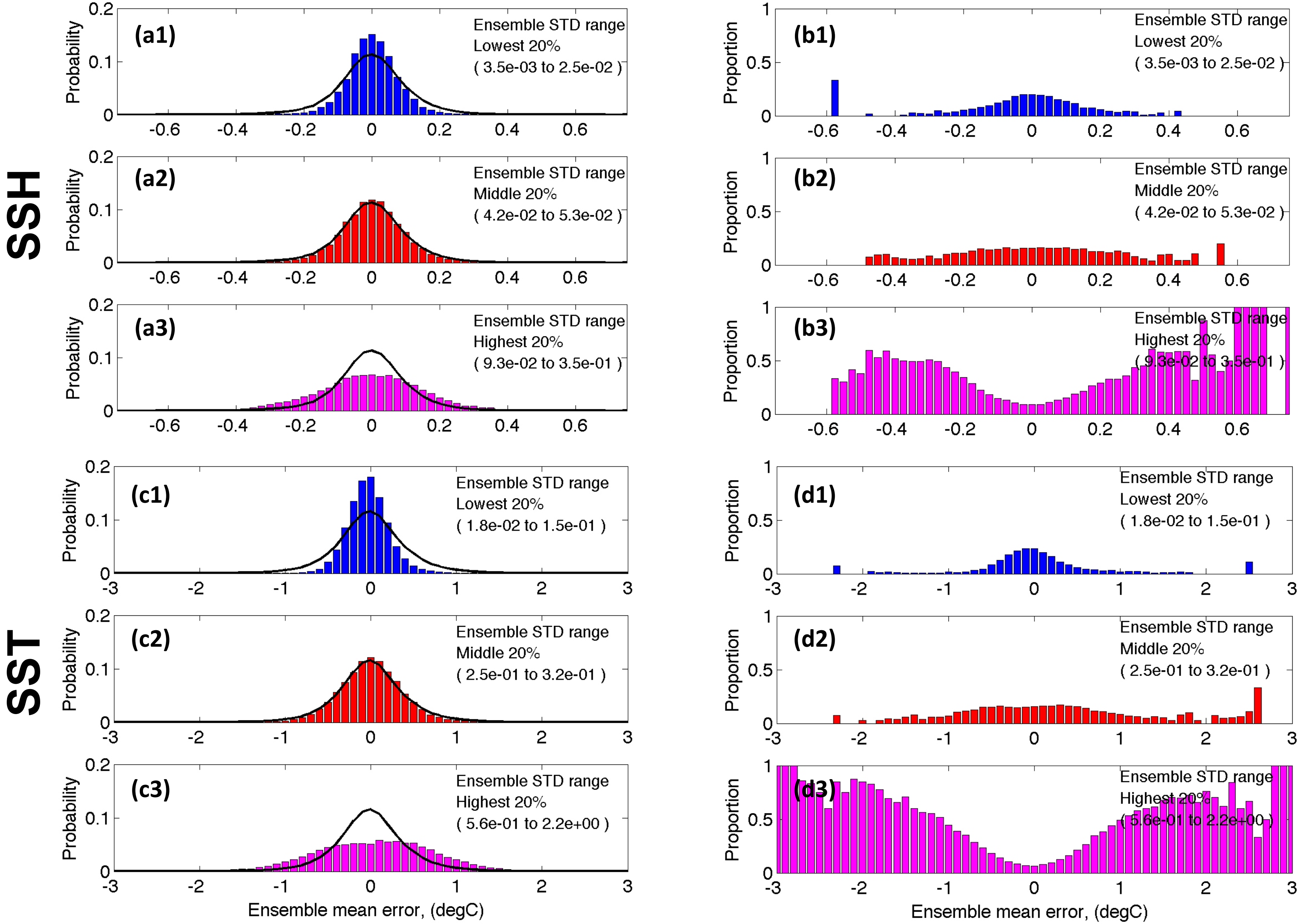
where the normalising standard deviation is amended to include the observation error variance to match the expected variance of the ensemble mean error, equation (4). Our hypothesis is therefore that for a well-behaved ensemble where equation (7) converges to the model error variance, ε_Z will represent a unit-normal distribution.



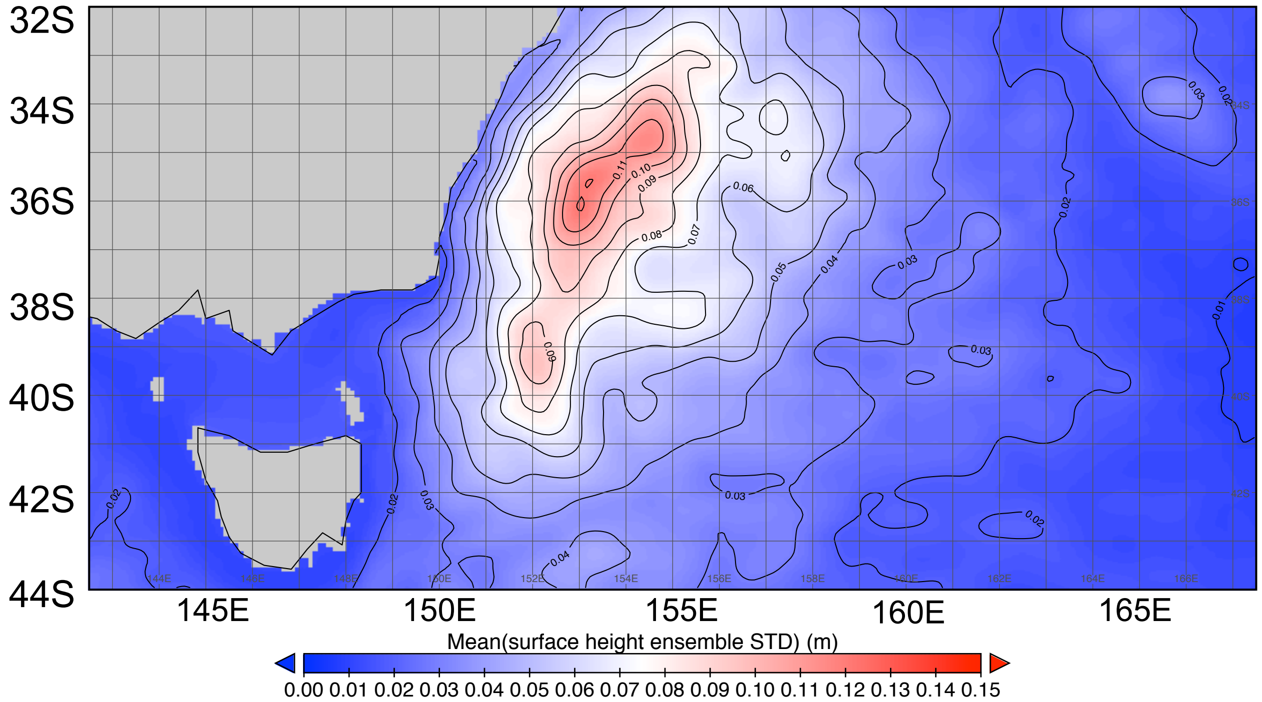
(a)
(b)
(c)
(d)
10N
EQ
10S
20S
30S
40S
50S
60S
100E
120E
140E
160E
Latitude, (degreeN)
Longitude, (degreeE)
STD normalised error
STD normalised error ratio (an/fc)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5


SSH
SST
East Australian Current
Normalised std = 1.35
Obs error std = 0.05
Normalised std = 1.04
Obs error std = 0.2
Normalised error
Ensemble STD (m)
Latitude, (degreeN)
Longitude, (degreeE)
83rd percentile normalised error
10N
EQ
10S
20S
30S
40S
50S
60S
100E
120E
140E
160E

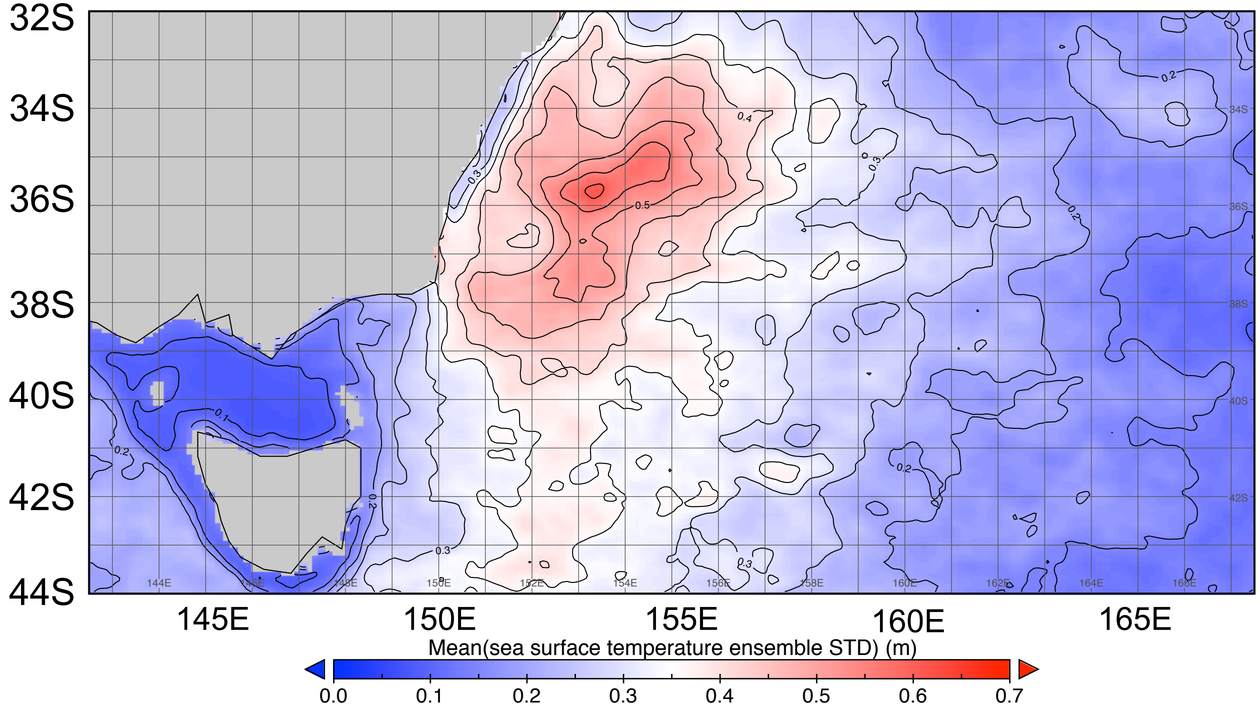
Four-cycle ensemble verification



SSH
Annual average ensemble STD
2013 - 2015



SST
Annual average ensemble STD
2013 - 2015



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