Observation Impact in a Regional Reanalysis of the East Australian Current System

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Key points

- Combining observations with a numerical model of the EAC, we reveal which observations contribute most to changes in the modeled estimates of EAC transport and Eddy Kinetic Energy
- For the metrics used, observations taken in regions with greater natural variability contribute most
- Using model physics to compute analysis increments, observation impact is far reaching: upstream and downstream, and forward and backward in time

Reanalysis Description (2 years, 2012-2013, Kerry et al. 2016)

- Regional Ocean Modeling System (ROMS), free-surface, hydrostatic, primitive equ. model
- Variable cross-shore horizontal resolution - 2.5km over continental shelf and slope to 6km offshore, 5km in alongshore direction, 30 vertical terrain-following s-layers
- Boundary and initial conditions from the BRAN3p5 reanalysis (11 km resolution, Oke et al. 2013)
- Atmospheric forcing from BOM ACCESS-R atmospheric model (12 km resolution)

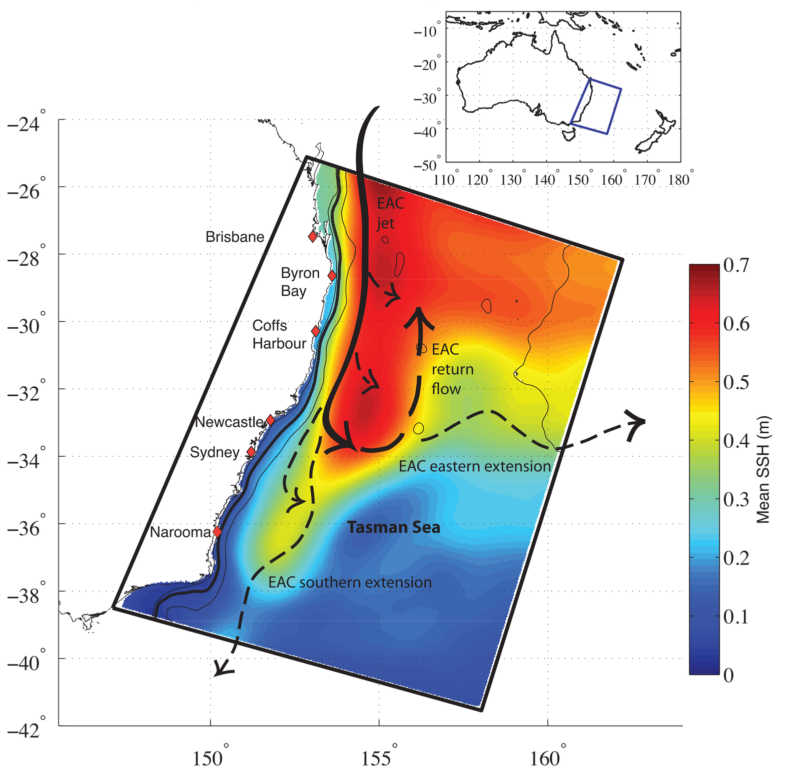

Fig. 1. Model domain showing mean SSH from 22-year model simulation and schematic of the EAC System adapted from Oke et al. 2018. Black solid lines denote permanent currents and black dashed lines denote transient currents associated with ``eddy trains''. Model bathymetry contours at 100m, 200m (bold) and 2000m are shown.

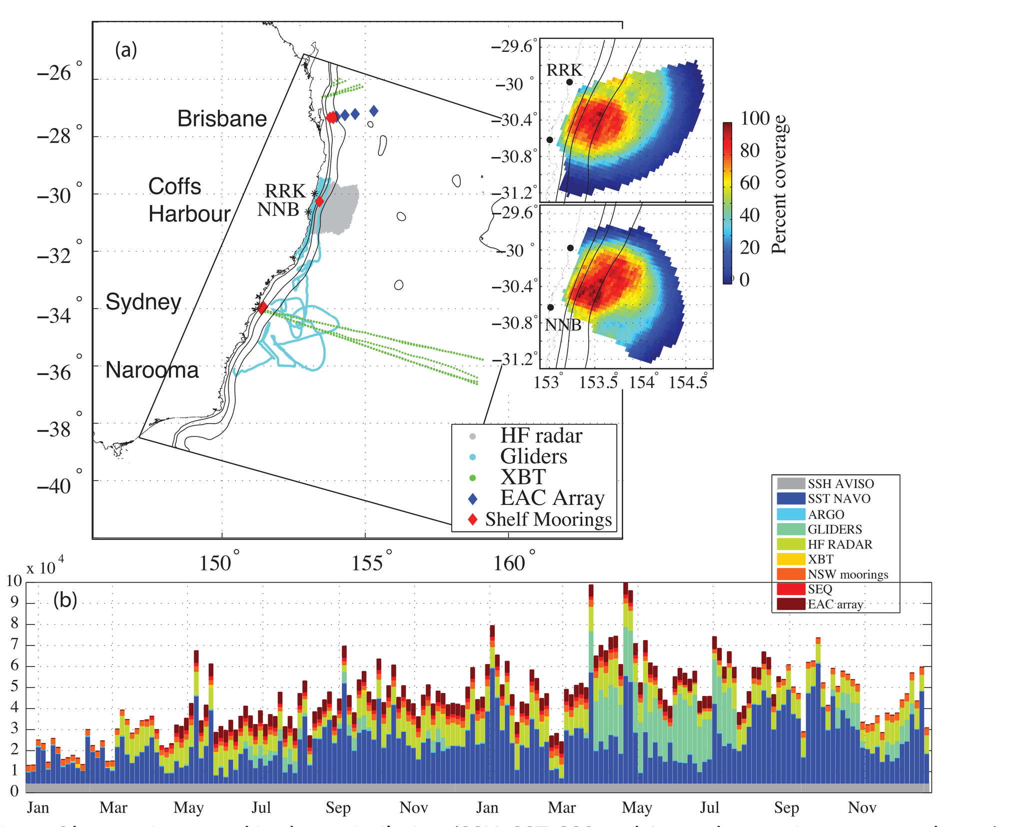

Fig. 2. Observations used in the assimilation (SSH, SST, SSS and Argo observations are not shown), (a). Insets show the percentage coverage of the surface radial data from the two HF radar stations. Number of observations from each observation platform in each 5-day assimilation window over the 2-year reanalysis, (b)

- Incremental Strong Constrainst 4-D Variational Data Assimilation
- Five-day assimilation windows, 15 inner loops, 1 outer loop, **P** estimated following Weaver and Courtier (2001).

- Observations
  - Sea Surface Height (SSH), AVISO daily gridded (1/3° x 1/3°) mean sea level anomaly data.
  - Sea Suface Temperature (SST), US Naval Oceanographic Office's Global Area Coverage Advanced Very High Resolution Radiometer level-2 product (NAVOCEANO's GAC AVHRR L2P SST, ~4km x 4km).
  - Argo Floats, 1229 profiles, temperature and salinity of the upper 2000 m.
  - Gliders, 8 autonomous glider missions from Jun. 2012 - Dec. 2013, temperature and salinity in upper 1000m.
  - Shelf Moorings, Two moorings off Sydney, one mooring off Coffs Harbour (NSW moorings). Two shelf moorings off Brisbane (SEQ). Temperature, salinity and velocities throughout the water column. Tides removed, applied 6-hourly.
  - HF Radar, Surface radial currents from HF Radar at Coffs Harbour, ~1.5 km resolution. Daily averaged radial current data assimilated.
  - Deep-water mooring array (EAC Transport Array), Temperature, salinity and velocity throughout the water column. Tides removed, applied 6-hourly.

- Reanalysis performance

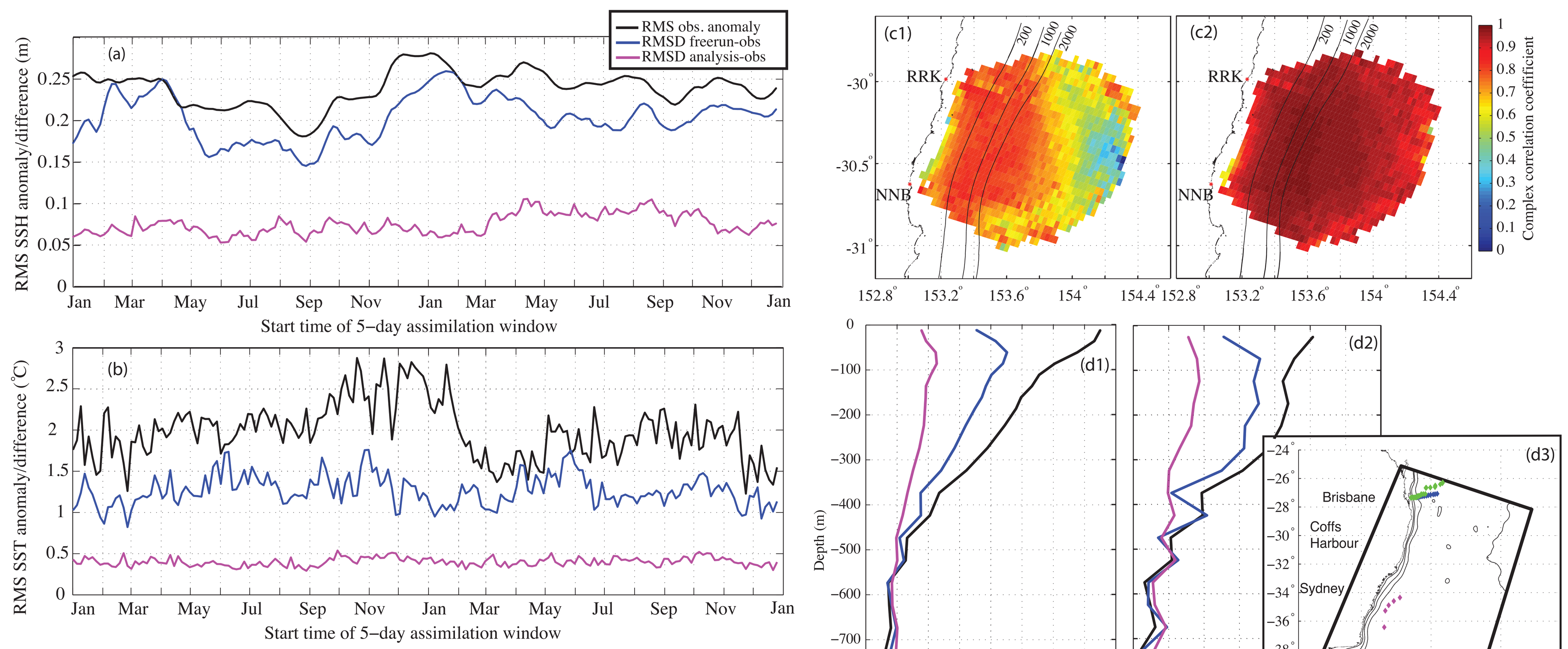

Fig. 3. Time-series of spatially-averaged RMS SSH observation anomaly, RMS SSH difference between the free run and observations, and RMS SSH difference between the analysis and observations, for each assimilation window, (a). As in (a) but for SST, (b).

Complex correlation of surface velocities computed from the assimilated HF radar radials, and surface velocities computed from the corresponding free run (c1) and analysis (c2) radials. 200m, 1000m and 2000m bathymetry contours are shown.

RMS potential density observation anomaly and RMS difference between the free run and observations, and the analysis and observations for Argo float observations (d1). As in (d1) but for independent (non-assimilated) CTD cast observations (d2). Observations are grouped into nominal depth bins of 50m. Locations of the CTD casts are shown in (d3).

Observation Impact (Kerry et al. 2018))

Circulation metrics - scalar quantities that describe a circulation feature of interest.

EAC Volume Transport - poleward transport across zonal cross-sections (Fig. 4a)

$$J = \frac{1}{T \times 10^6} \int_{t_0}^{t_0+T} \int_{-D}^{0} \int_{x_0}^{x_i} (\mathbf{v}) dx dz dt$$

where T is the time over which the transport is evaluted , $-D$ to 0 is the depth range, x_0 to x_i is the shore-normal distance, and v is the meridional velocity component.

Eddy Kinetic Energy (EKE) over a region of the Tasman Sea (Fig. 4a)

$$J = \frac{1}{TDA \times 10^4} \int_{t_0}^{t_0+T} \int_{-D}^{0} \int_{x_0}^{x_i} \int_{y_0}^{y_i} \left((u-\bar{u})^2 + (v-\bar{v})^2 \right) dy dx dz dt$$

where T is the time over which the EKE is evaluted, $-D$ to 0 is the depth range (0-450m), A is the defined area, and u and v are the velocities.

Observation Impact Computations - we quantify how each observation type contributes to the difference between the analysis and prior (forecast) J.

The difference, $\Delta J = Q(\mathbf{x}_a) - Q(\mathbf{x}_f)$, is given by,

$\Delta J = \mathbf{d}^T \mathbf{K}^T \frac{\partial Q}{\partial \mathbf{x}_f}$ for a first order expansion and, $\Delta J = \frac{1}{2} \mathbf{d}^T \mathbf{K}^T \left[\frac{\partial Q}{\partial \mathbf{x}_a} + \frac{\partial Q}{\partial \mathbf{x}_f} \right]$

for a second order expansion (used for EKE), where **d** is the innovation vector, **K** is the Kalman Gain matrix and x_a and x_f are the analysis and forecast state vectors.

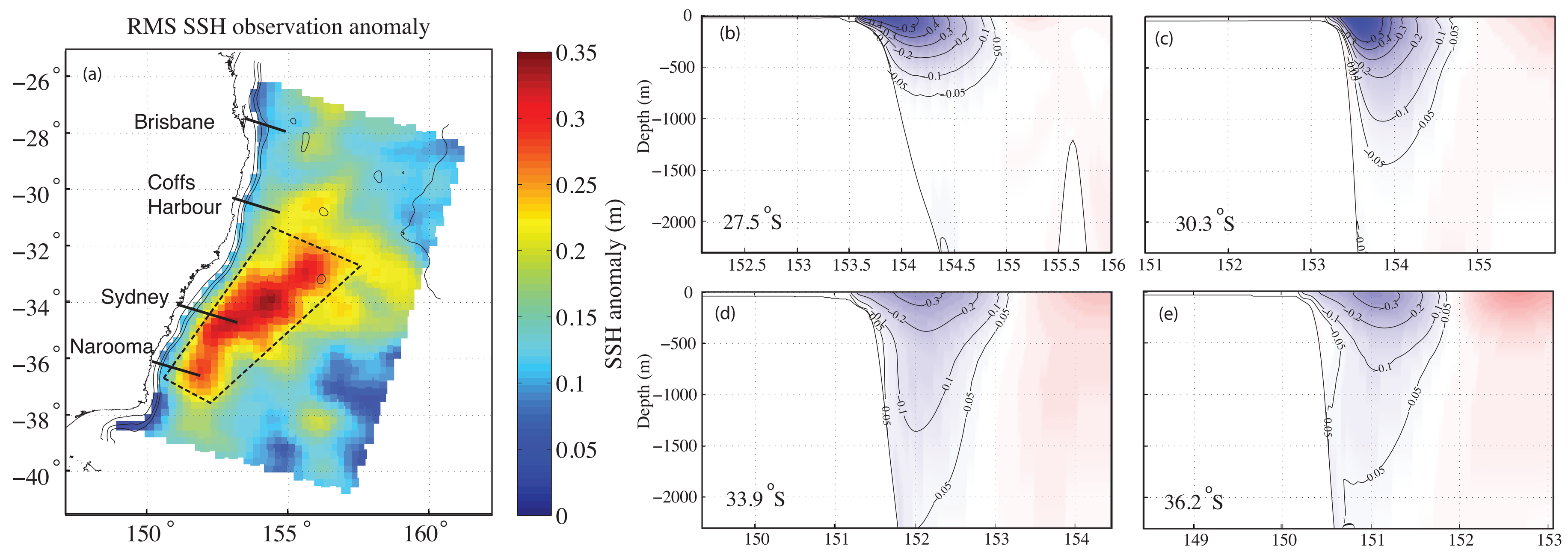

Fig. 4. RMS SSH anomalies from 10 years of AVISO data, (a). The black solid lines show the sections across which the alongshore volume transport is computed, the black dashed line shows area over which spatially-averaged EKE is computed.
Mean alongshore velocity from the 2-year reanalysis through shore normal sections crossing the coast at Brisbane (27.5S, (b)), Coffs Harbour (30.3S, (c)), Sydney (33.9S, (d)) and Narooma (36.2S, (e)).

Summary of Results

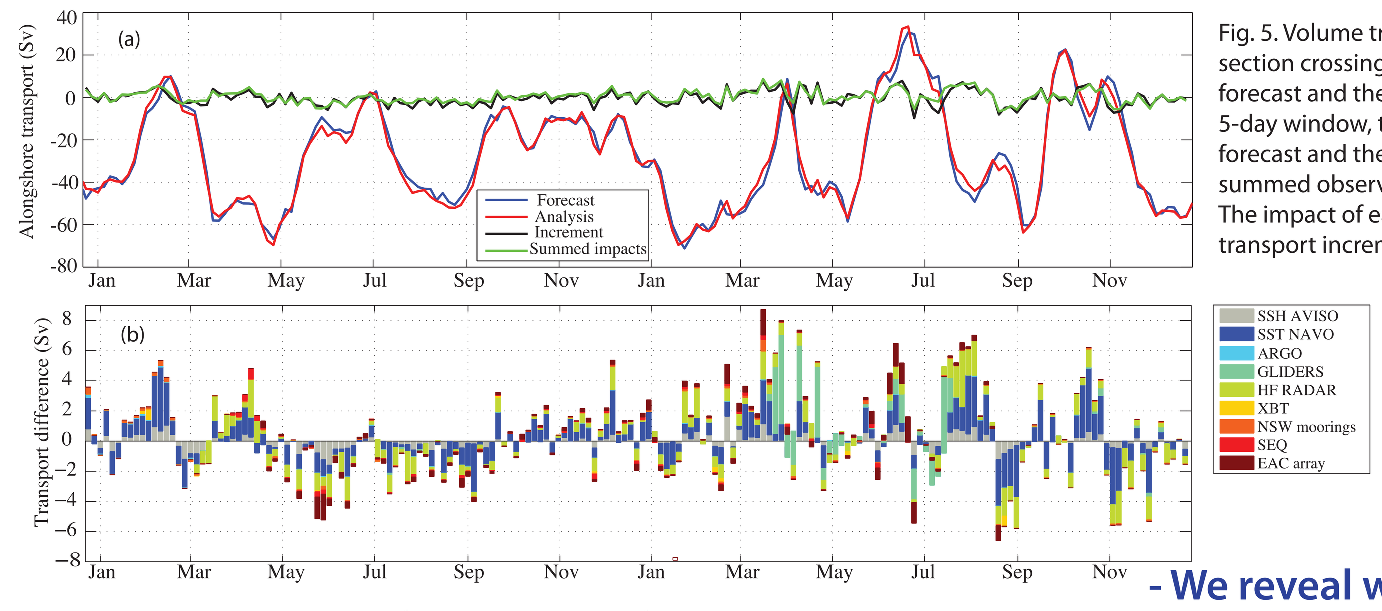

Fig. 5. Volume transport through the shore normal section crossing the coast at Sydney (33.9S) for the forecast and the analysis, averaged over each 5-day window, the difference in transport between the forecast and the analysis (the increment), and the summed observation impacts, (a)
The impact of each observation platform on the transport increment for each 5-day window, (b).

Table 1: Average percentage impact of each observation platform over the 2-year reanalysis period, for alongshore transport through the four sections and spatially-averaged EKE (Fig. 4a).

	Mean % no. obs.	Mean % impact				
		27.5° S	30.3° S	33.9° S	36.2° S	EKE
SSH AVISO	11.77	10.67	10.36	12.46	13.76	11.76
SST NAVO	43.62	38.48	35.86	43.11	42.97	43.49
SSS Aquarius	0.35	0.005	0.005	0.005	0.006	0.006
Argo	1.03	0.85	0.86	0.84	1.01	0.93
Gliders	8.85	6.10	5.48	6.87	5.68	7.24
HF radar	17.22	28.62	36.41	23.81	23.80	23.90
XBT	0.19	0.37	0.52	0.64	0.58	0.61
NSW moorings	6.73	2.74	2.83	2.48	2.43	2.61
SEQ	2.40	2.80	1.62	2.08	1.84	2.20
EAC array	7.83	9.38	6.06	7.71	8.69	7.26

Note. AVISO = Archiving, Validation and Interpretation of Satellite Oceanographic data; EAC = East Australia Current; HF = high frequency; SEQ = South East Queensland; SSH = sea surface height; SSS = sea surface salinity; SST = sea surface temperature; NAVO = Naval Oceanographic Office; NSW = New South Wales; XBT = expendable bathythermograph.

- **We reveal which observations have the greatest impact on the modeled estimates of EAC transport and EKE** (Table 1).
  - SST, HF radar, SSH, gliders and EAC mooring array (in that order).
- The impacts are flow dependent and vary considerably from one window to the next (Fig. 5)
- The HF radar has a disportionality high impact relative to number of observations (Table 1)
- **Observation impact is far-reaching; up and downstream** and forward and backward in time, e.g. HF radar, EAC array (Table 1) and information must be carried by processes other than advection.

- HF radar observations are particularly useful in constraining the EAC where it is mostly coherent. Satellite observations are more useful, on average, where transport is eddy driven (Table 1).
- **Observations taken in regions with greater natural variability are most impactful.**
  - SSH and SST observations of the region of elevated eddy energy between 32-37S (Fig. 4a) have more impact per observation than the same observations taken elsewhere (Fig. 6)
  - Observations in the upper 400 m of the water column have more impact than deeper observations (Fig. 7), as they sample the depth region of greatest uncertainty (the mixed layer and pycnocline).
- Glider observatons have large impacts when they sample eddies offshore of Sydney, as they provide detailed information on the typically undersampled subsurface (e.g. Fig 5 Aprl-May, Fig. 7) .
- Profiling observations from Argo floats and XBTs have small total impacts (Table 1) as they are temporally and spatially sparse but high impacts relative to the number of observations (Fig. 6, Fig. 7 (see caption re. XBT)) as they provide new information about the subsurface ocean.
- **Observation impacts are dependent on the chosen metrics and the DA model configuration**, such as prior choices of observation and background errors, encompassed in K.

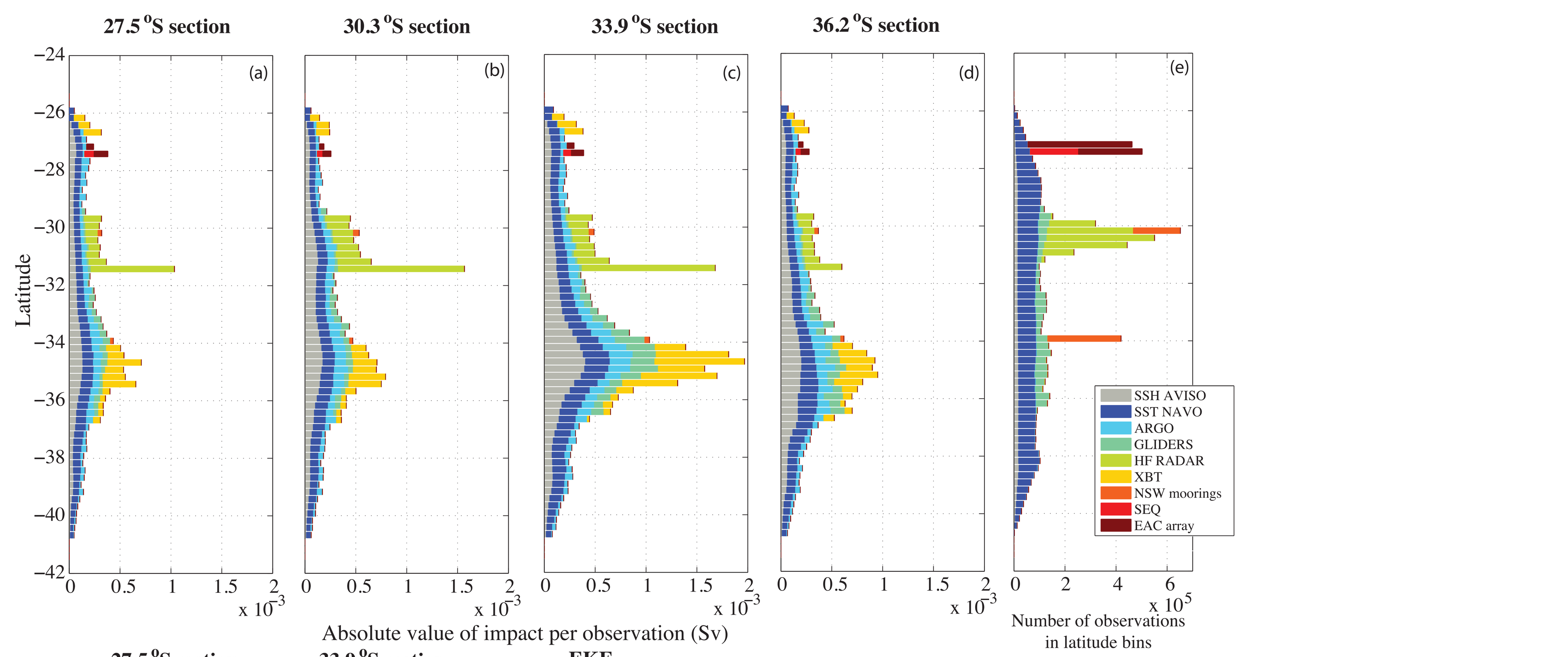

Fig. 6. (above) The observation impacts on transport through the four shore normal sections grouped into latitude bins of 0.25 degrees. Summed absolute value of impacts for observations from each observation platform in each bin over the 2 years normalised by the number of observations (a-d), and the number of observations in each bin (e).

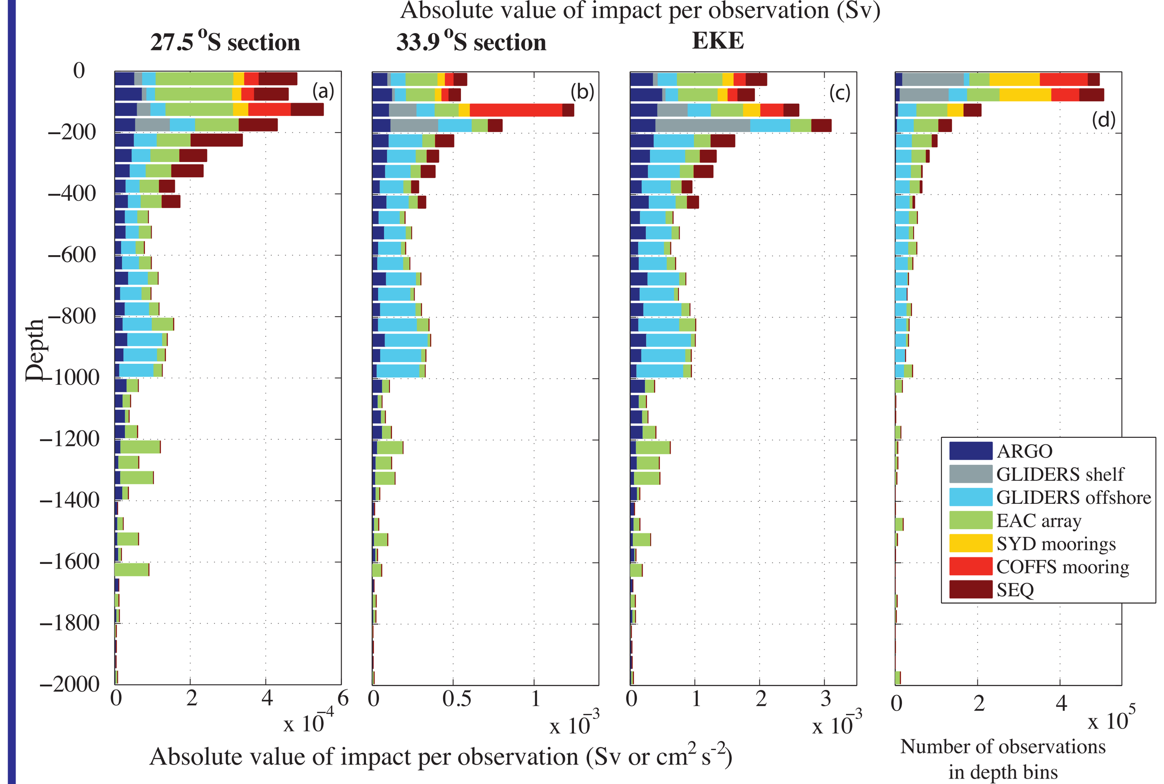

Fig. 7. (left) The observation impacts on transport through the 27.5S and 33.9S sections and spatially-averaged EKE over the Tasman Sea, grouped into depth bins of 50m. Summed absolute value of impacts for observations from each observation platform in each bin over the 2 years normalised by the number of observations (a-c), and the number of observations in each bin (d). Note that the XBT data have not been included in these figures as the summed impacts are so small relative to the other platforms but their impact per number of observations are large (of similar magnitude to all other platforms added) making Figures 7a-c difficult to interpret.

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