FORECASTERS’ FORUM

Sea Level Anomaly Forecasts on a Coastal Waveguide

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(Manuscript received 12 December 2018, in final form 12 December 2019)

ABSTRACT

An approach to reduce forecast data to coastal waveguide coordinates is described and demonstrated, informed by the literature on coastally trapped waves (CTWs). All discussion is limited to the Australian mainland but the approach is generally relevant to regions where CTWs influence sea level, including the Americas and Africa. The approach does not produce new forecasts, but aims to focus forecaster attention on aspects of sea level forecasts prominent on the long Australian coast. The approach also explicitly addresses spatial issues associated with measuring coastal paths. Coastal paths are scale dependent and forecast models discretize the coastal boundary differently. A well-defined coastal path is required for the quantitative application of CTW concepts such as propagation distance and offshore direction. The relevance of coastally trapped signals and remote forcing is documented in the oceanographic literature, but is effectively unknown to the general public and rarely mentioned in press reports of sea level events such as nuisance flooding. Routine presentation of forecast guidance in waveguide coordinates could contribute to the transfer of oceanographic research understanding into forecast narratives. In addition, the approach can facilitate quantitative forecast evaluations that target CTW properties. Two ocean forecast systems are contrasted in this framework for the Australian mainland. One year of daily forecasts are compared, with indications that model baroclinicity is of practical relevance.

1. Sea level anomalies and forecast narratives

Many activities are organized around expectations of coastal water levels over the next few days, including mitigation of nuisance coastal flooding (Sweet et al. 2014; Hague et al. 2019).

Still water levels (Pugh and Woodworth 2014) at the coast are not just a matter of tidal patterns and local storms, but can also be influenced by remote forcing via coastally trapped wave (CTW) mechanisms. While CTWs have received much academic attention (section 2), it seems the application of the CTW perspective to the evaluation of model guidance and the creation of forecast narratives is routinely absent in the Australian setting. This leaves both forecasters and the public with a common assumption that coastal sea level anomalies are driven solely by local weather. Such assumptions may arguably be reinforced by the manner in which forecasts and evaluation metrics are routinely presented.

Very high-impact, short-scale extremes such as tropical cyclones (McInnes et al. 2016) are obviously important to coastal decisions but are not the target of this discussion.

Coastal sea level anomalies are in practice almost always interpreted with reference to conventional tide tables (PCTMSL 2018). While sophisticated sea level decision support systems do exist for some customers (James and Hibbert 2017), in general circumstances the coastal community consults tide tables in light of recently observed anomalies and anomaly trend expectations. Expectations of how anomalies (or “residuals”) may change over the next few days can be based on recent observations, heuristics, and numerical forecast guidance (Taylor and Brassington 2017; Horsburgh and De Vries 2011). Numerical forecasts are the focus of this discussion. Numerical forecasts of sea level anomaly fields are commonly viewed as topographic maps like Fig. 1. Coastal propagation of sea level features can be noticed on animated versions of such maps if the...
spatial scope is sufficiently large. But with a wide scope the coastal signal is often visually swamped by the diverse phenomena thus included, such as the eddies shown off the east coast of Australia. In contrast to the "map" view, consider the propagation-focused phase-space guidance available to tropical weather forecasters (Wheeler and Hendon 2004) that reduces the many dimensions of a numerical forecast to the propagation of particular patterns around the equatorial waveguide.

Regardless of the forecast guidance source, narrative attribution can be a factor that influences decisions. If residents are told that "...westerly winds push tides from the bay..." (Melbourne Water 2018), then they may be perplexed to find their sea gate closed on a windless day. Public messaging about local strong winds and low pressure are common and useful enough: "...storm surge is caused when a low atmospheric pressure meteorological system and strong onshore winds force sea levels to rise above normal levels..." (Brisbane City Council 2018). But the role of remote winds, wind orientation, and persistent and propagating sea level signals seems to be effectively ignored from such descriptions.

Essentially, we perceive a gap between research understanding and daily forecast narratives. Routine availability of waveguide views into numerical forecast data may contribute to the transfer of academic understanding to a wider audience and ultimately to improved communications regarding coastal sea level. Waveguide-based methods to intercompare heterogeneous forecast data may also facilitate the connection between aspects of the research literature to operational verification and systems development.

We demonstrate one approach for projecting operational ocean forecast data into waveguide coordinates. While our scope is restricted to the Australian mainland, the concepts may also be relevant to other regions.

2. Coastal waveguide perspective
   a. Oceanographic literature

The oceanographic literature addressing CTWs is extensive and has prominently featured the Australian mainland. The literature has established a common
spatial paradigm (Brink 1991) with directions relative to the coast as illustrated in Fig. 2. In this context, the nomenclature of “alongshore/longshore” and “along-shelf” are interchangeable. This CTW “natural coordinate” system (Gill 1982) arises from an interest in propagation along a long coastal waveguide. The coordinate schematic indicates an ideal of uniformity longshore and a cross shelf profile that is either flat or deepening monotonically away from a coastal boundary. This situation allows for the hybrid of propagation mechanisms involving gravity and potential vorticity, requiring topographic slope, and Rossby adjustment against a coastal boundary.

CTW dynamics are generally associated with sub-inertial frequencies, along-shelf scales of motion much greater than cross shelf, along-shelf propagation characteristics, and cross-shelf mode decomposition. Targeted campaigns have demonstrated the relevance of this theory to explaining nontidal oceanographic observations (Church and Freeland 1986; Merrifield 1992; Ding et al. 2012). Coastal trapping also plays an important role in the astronomical tide literature (Schureman 1971). The limits of CTW theory have been explored in the literature and these limits are relevant to application at routine weather forecast time scales. For instance,

- energy scattering and leakage (Middleton 1991; Merrifield and Middleton 1994; Yankovsky and Zhang 2017),
- near-inertial and superinertial frequencies (Dale et al. 2001; Dale and Sherwin 1996),
- small-scale geometrical irregularities (Wilkin and Chapman 1990; Liao and Wang 2018b),
- curvature of along-shelf geometry (Grimshaw 1977),
- sensitivity to model choice (Sansón 2012), and
- propagating atmospheric features at near resonant speeds (McInnes and Hubbert 2003).

b. How long is the coast and where is it?

Applying a CTW perspective to real geography raises the deceptively simple questions of how to measure the length of a propagation path and how to specify along and offshore directions. Such questions are not problematic for the equatorial waveguide. But for measuring a waveguide associated with land/sea boundary raises the well-known “coastal paradox”; by which the length of a statistically fractal feature depends on the measuring scale (Mandelbrot 1967) [introduced by L. F. Richardson in another context (Vulpiani 2014)]. The literature on CTWs, which inherently involves coastlines, has not directly addressed the statistically fractal character in the attribution of a propagation distance, wind direction or the separation between tide gauges. Some nonoceanographic literature has however drawn connections in the opposite direction; between the complexity of the Australian coast and marine processes (Porter-Smith and McInlay 2012).

In addition to the nontrivial task of measuring a coast, each discretized model carries its own representation of the coastal interface, often via a binary land/sea mask. The defacto location of a numerical coastline described by a mask can differ noticeably between models even if based on the same foundational bathymetry. Such differences are especially significant with comparing models configured at different spatial resolutions.

This situation motivates the application of an algorithmic method to realize a set of model-independent “waveguide” coordinates. Fundamentally, such an algorithm is a means of defining a coastal path and associated local horizontal directions given a well-defined length scale. For the present demonstration, a version of the traditional “divider walk” (Xu et al. 1993) algorithm provided a tractable approach to develop a path using the Geospatial Data Abstraction Library (GDAL; GDAL/OGR 2018). The path used was based on a relatively high-resolution (~250 m) coastline dataset independent from the forecast models themselves. Figure 3 demonstrates the dependence of waveguide length on divider scale by multiple applications of the algorithm. The dependence results in an estimate of an effective fractal dimension of ~1.08, comparable to those summarized in Ma et al. (2016).

We emphasize that the idea is to define a longshore length scale in the realization of the waveguide path, such that distances and directions have an explicit foundation. The particular algorithm and scale are not asserted as being unique or optimal and others may...
present benefits [e.g., the rolling ball method of Hall (2002)]. For this implementation, the length scale of each divider segment is set proportional to a local Rossby radius of deformation (Gill 1982, p. 205), which is well-defined for the Australian continental path shown. This radius depends only on latitude and a wave celerity, which we have configured to match the barotropic mode at a nominal depth of 20 m.

This configuration is intended to roughly target the longshore scales associated with CTW generation, but alternative realizations are plainly possible. The choice of scale primarily impacts the sample directions and derivation of wave speeds from model output—it has no impact whatsoever on the source model’s representation of phenomena. Decomposition of wind vectors into along and offshore directions is closely tied to the path definition. Sensitivity of the results to the details of path realization are not explored in this study but will be pursued in future work.

Figure 4 shows the waveguide path referenced in subsequent figures. The shorter lines at each vertex indicate the local offshore direction used to decompose wind vectors and sample coastal cells. Only the Australian mainland is included with arbitrary start and end points. Signal expressions around Tasmania or any smaller islands are not addressed.

c. Projection onto the waveguide path

The waveguide path is based on an independent high-resolution coastline and choice of length scale. Different data sources were projected onto this path using an algorithmic sampling method. The sampling method aims to select only grid cells represented as “coastal” in each model, and to associate locations with the waveguide via orthogonal projection. This is effectively a restricted type of nearest-neighbor sampling with no interpolation between grid points.

For each cross-shore profile line in Fig. 4, the algorithm essentially looks for the best matching coastal cell by starting out to sea and stepping inwards until the last “wet” cell is found. Each sample is associated with the longshore distance coordinate of the corresponding waveguide vertex.

For tide gauge observations, the inverse process was applied as a geometric projection to assign waveguide coordinates. The projection mapped each tide gauge location to the single closest point on the waveguide following a bearing perpendicular to the matched line segment. An arbitrary limit of 50 km was applied to limit the spatial extent of the automated projection, which otherwise could match distant island locations to the coastal path.

To facilitate additional postprocessing of the waveguide sampled datasets a two stage linear interpolation process was applied to reduce the data further to a common regular time and space grid for differencing and correlation operations.

3. Data sources from the operational center

This study originates from the application of a CTW perspective within an operational setting. Key details of
the operational data sources used are outlined below. Data availability has limited our comparison to the 1-yr period from 10 April 2018 to 10 April 2019.

a. Surface winds and pressure from NWP: ACCESS-G

Atmospheric forecast inputs were taken from the global numerical weather prediction (NWP) system ACCESS-G (Bureau of Meteorology 2016). It is not coupled with any ocean model and employs an observational SST analysis, fixed over each forecast, as a lower boundary condition. These fluxes are generated on a N512 Gaussian grid with an indicative spatial resolution of ~25 km.

b. OceanMAPS: Data assimilating global primitive equation forecasts

The 7-day sea level anomaly (SLA) forecasts were taken from the near-global Ocean Model, Analysis and Prediction System (OceanMAPS). OceanMAPS has now been in operational production for over 10 years across several version upgrades (Brassington et al. 2007; Bureau of Meteorology 2007, 2011; Brassington et al. 2012). The dynamic ocean model component of OceanMAPS is based on the Modular Ocean Model (MOM version 4.1) (Griffies et al. 2008) configured with a 0.1° × 0.1° regular structured horizontal resolution, hydrostatic free surface, 51 z levels with 5-m top cell, 15-m minimum column depth, and a split-implicit scheme, where the barotropic calculation is performed at a finer time stepping. Atmospheric fluxes from ACCESS-G including surface stress are imposed directly. Note that barometric pressure and gravitational tidal forces are intentionally not applied.

Initial conditions for the ocean state are constrained using an ensemble optimal interpolation data assimilation scheme (Oke et al. 2008; Sakov 2014). Tide gauge observations are not assimilated and are independent. Satellite altimeter observations of sea level are assimilated, but not inshore of the shelf break, nominally cut off at the 200-m isobath. Background error covariances are non-Gaussian and based on physical scales resolved by the model.

OceanMAPS produces a new ocean state forecast each day using a multicycle ensemble schedule (Brassington 2013). Concatenated OceanMAPS data for the period are shown in Fig. 5.

c. Surge: Regional shallow-water depth integrated

The 3-day surge forecasts are taken from a national domain 2D configuration of ROMS (Shchepetkin and McWilliams 2005), which has been brought into operational production more recently (Allen et al. 2018). This operational system produces new forecasts on a 6-hourly warm start cycle with atmospheric forcing from the regional NWP forecasts (ACCESS-R). No data assimilation is employed, and the regional domain is not nested in any larger model. While no baroclinic dynamics are included, the system offers relatively high spatial resolution of ~2 km and alignment with weather forecasts from the more rapidly updated regional NWP system.

For the purposes of this study, a variant of the operational 2D ROMS forecast schedule was run using the identical NWP inputs to the 3D global model, namely ACCESS-G. Unlike the operational surge system, barometric pressure fields were not applied to this variant to facilitate direct model intercomparison with OceanMAPS. Henceforth, this system will be referred to as “Surge.” While this is not strictly operational output, utilizing the common NWP source facilitates more meaningful contrast of the ocean model types. Modifications beyond the exchange of source NWP were avoided and forecast length was kept at 72 h.

d. Adjusted tide gauge observations

In situ coastal sea level observations were obtained from a heterogeneous set of real-time tide gauges. Many more tide gauges are known to exist within our spatial domain, but we have intentionally used only data-streams available in real time to Bureau operations. The resulting spatial sampling of the network is very irregular. Coverage along the east coast is most comprehensive. The fact that only a subset of these available tide gauges are collocated with barometer instruments influenced the choice to apply a NWP-based inverse barometer adjustment. This local inverse barometer approximation approach is simplistic (Mathers and Woodworth 2004) but pragmatic and formatted as follows: $\eta_{IB} = (p_{NWP} - p_{ref})/\rho g$, where reference pressure is fixed at $p_{ref} = 101.325$ Pa, and bulk seawater density is also kept fixed at $1027 \text{kg m}^{-3}$. Several steps of processing were applied to obtain comparable adjusted residuals: 1) temporal homogenization to 1-h averages, 2) subtraction of standard harmonic tide signal, and 3) adjustment using local inverse barometer approximation based on NWP pressure field.

4. Viewing operational data in CTW coordinates

CTWs around the Australian mainland have been recently discussed in the context of general primitive equation ocean models by Woodham et al. (2013) and Liao and Wang (2018a); and in the northwest of Australia by Maxime and Ming (2019). The models discussed are closely related to the operational OceanMAPS system. In line with the previous
literature, these papers address propagation speeds but not how distances between sample locations were measured. We assert that propagation quantities are rendered more meaningful in this context when the propagation path is made explicit. The explicit waveguide path approach described in section 4b facilitates the generation of new guidance to focus attention on coastal patterns and helps clarify the attribution of propagation quantities. Figure 5 shows a concatenation of the first 24 h of each OceanMAPS forecast as a familiar “trough-and-ridge” plot (Hovmöller 1949). Select place names around the Australian mainland are indicated for reference. Diagonal patterns sloping upward to the right are indicative of signal movement in an anticyclonic direction (counter clockwise for the Southern Hemisphere). Both positive and negative signals of this type are evident in many instances. In contrast, essentially flat (i.e., not propagating) patterns that rise and fall with diurnal frequency are seen in the tropical sections of the domain.

This projection approach is not limited to a single model or quantity; Fig. 6 illustrates an application to several forecast sources sharing a single base date. A novel aspect of the application to surface winds (a vector quantity) is the decomposition into waveguide-based components in which the directions are directly related to the length scale specified. Surface winds are the primary driver of synoptic-scale sea level anomalies and

**FIG. 5.** Concatenated first day of OceanMAPS SLA forecasts for the comparison period; the time series at each position is centered by removal of the sample mean. Note the distance units are meters and range to $-11,000$ km.
the present intercomparison is founded on identical atmospheric forcing source being applied to both models. As noted in section 4c the 2D surge forecasts are restricted to 3 days. Broad correspondence of wind stress \( \tau \) and sea level patterns can be seen, especially along the southern shelves as described by McInnes and Hubbert (2003). In contrast a relatively regular diurnal pattern is notable in the tropical sections.

a. Forecast differences viewed in waveguide coordinates

In addition to providing for focused visualizations, this data reduction method facilitates model intercomparisons that target CTW features. The following examples contrast behavior of the barotropic surge model with the lower-resolution but dynamically rich global ocean forecasts. Understanding the limitations of dynamic surge forecasts with regard to CTWs has been recently highlighted as important in the Australian context (Hetzel et al. 2017).

b. Apparent propagation and persistence

Unlike studies that target the isolation of CTWs (Maiwa et al. 2010), operational users need not distinguish between forced and free propagation as the apparent progress of sea level patterns is of primary
interest. Regardless of trapping mechanisms, atmospheric forcing patterns can effectively move around the Australian coast—notably as midlatitude weather systems travel zonally. This movement is reflected by the lagged autocorrelation of wind stress in Fig. 7. Apparently anticyclonic movement is prominent along the zonally aligned southern coast but may also occur along nonzonal sections of the coast as patterns of wind alignment progress in time.

We suggest that a forecast like that shown in Fig. 6 may be helpfully narrated as “a pattern of sea level anomalies moving along the southern mainland and up the New South Wales (NSW) coast over the next 7 days” without any reference to CTWs or physical processes. While attribution to can aid forecaster interpretation, it is not the primary concern of public narratives.

Inspection of Fig. 5 shows visually coherent structures from which apparent propagation speeds can be derived, corroborating the ~3.4 m s\(^{-1}\) speeds described by Woodham et al. (2013) and others along the east coast. Though without temporal filtering, faster features more indicative of Kelvin waves (~25 m s\(^{-1}\)) are also present. An implication of Fig. 3 is that such speed estimates are dependent on the length scale used to measure the coastal path.

c. Wind stress orientation and correlation

While subinertial CTW theory is formulated only in terms of longshore winds, the onshore component is also a factor in sea level forecasts (Tilburg and Garvine 2004). Propagation of signal along the waveguide means that nonlocal winds can also be important, a fact that we assert is not commonly appreciated by forecasters or the general public.

Lagged cross correlations between the datasets projected into waveguide coordinates are relatively simple given that the data are reduced to a common 1D spatial path. Some of the structure in these correlations simply reflect details of interpolation and spatial sampling, but meaningful interpretation is still possible, recalling that the same atmospheric forcing is apply to both models.

At zero lag, Fig. 7 provides some indication of typical length scales of the forcing weather systems. The peculiar decomposition into longshore and cross-shore directions (wind stress \(\tau_{\text{along}}\) and \(\tau_{\text{on}}\)) imposed by the geometry of this path realization is also apparent, with much shorter scales at coastal “corners” such as Cape Leeuwin. Correlations between wind components and modeled sea level at a lag of nearly 3 days are shown in Figs. 8 and 9. Spatially coherent correlation peaks offset to the right of the main diagonal in these figures are interpreted as systematic anticyclonic signal propagation. Contrasts between the models are evident on the east coast north of Sydney that may reflect the role baroclinic modes.

d. Baroclinicity and shelf resolution

Differences between the interpolated tide observations, OceanMAPS, and Surge forecasts are shown in Figs. 10 and 11, respectively. The relative spatial density of available tide gauge data along the east coast is prominent. Differences between the two models are shown in Fig. 12. Many of the differences are again simply issues of spatial sampling, especially

![Fig. 7. Cross correlation at lag of zero hours: \(\tau_{\text{along}}\) lagging (a) \(\tau_{\text{along}}\) and (b) \(\tau_{\text{on}}\).](image-url)
for the surge model around the bays near Northwest Cape. However, structured patterns of difference will at least partially reflect systematic deficiencies in each model.

The relatively large difference between the two forecasts may reflect the lack of baroclinicity in the Surge model. Dynamics relevant to some forms of CTW propagation are excluded from an ocean model without any buoyancy stratification. Apparently propagating patterns of additional signal are present in the OceanMAPS forecasts starting from around Cape Leeuwin. For instance, the feature on the east coast in mid-May has an apparent celerity of $\sim 3.4 \text{ m s}^{-1}$, consistent with CTW features reported by Woodham et al. (2013).

Liao and Wang (2018a, p. 312) specifically comment that “…data from the OFAM reanalysis in Woodham et al. (2013) were based on a horizontal resolution of 10 km which was not high enough for the Australian east coast …[and] vertical resolution [details] … could lead to further inaccuracy in …CTW amplitude calculation [s].” Despite this coarse representation of the narrow east coast shelf, the fact that CTW-like features appear in the OceanMAPS sea level signal, but not in the higher-resolution Surge forecasts is interesting and possibly reflects an advantage in allowing at least some

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**Fig. 8.** Cross correlation at lag of 66 h: OceanMAPS response lagging (a) $\tau_{\text{long}}$ and (b) $\tau_{\text{off}}$.

**Fig. 9.** Cross correlation at lag of 66 h: Surge response lagging (a) $\tau_{\text{long}}$ and (b) $\tau_{\text{off}}$. 
representation of baroclinic modes. Figure 13 summarizes and contrasts the SLA forecast skill of the two systems for categorized lead times of 0–24 h (day 0), 24–48 h (day 1) and 48–72 h (day 2). Day-0 difference data is that shown in Figs. 10 and 11. On this measure, OceanMAPS notably outperforms the Surge forecast along the east coast from Eden to Fraser Island. As this section of the Australian coast is characterized by such a narrow continental shelf, better skill results from the model with lower horizontal resolution is at face-value surprising. But when this skill is viewed in light of a CTW perspective, it points to the east coast being a region where propagating sea level signals are significant and where representing baroclinicity provides a tangible advantage to the forecast model.

5. Discussion

We assert that a waveguide perspective can provide complimentary insight into the interpretation of daily sea level forecasts and assist in promoting the transfer of research understandings to daily operations. While the Australian coastline has been the sole focus of this study, the approach taken could also apply to similar long coastlines, including the Americas and Africa. Whether forecast narratives in those regions also underplay remotely forced coastal sea level is beyond our scope, but a waveguide perspective may offer some insight into explaining the Di Liberto et al. (2011) finding that a 5-day bias correction improved forecasts skill for particular depth-integrated surge models in a North American context.

The way that numerical forecast guidance is framed informs the forecast narratives that can ultimately influence decisions made at the coast. Given the apparently common overemphasis on the role of local weather effects on coastal sea level anomalies, a CTW perspective onto sea level forecasts may help direct attention to the relevance of broader longshore patterns and remote winds. Such a perspective could inform narratives...
without the need for reference to potentially obfuscating academic terms, for example: “...a pattern of sea level anomalies moving up the NSW coast over the next 3 days will raise sea levels...”

Beyond the application to daily forecasts, the approach presented will facilitate forecast evaluations that target coastal propagation. Coastal propagation characteristics are rendered more directly comparable by the reduction of heterogeneous gridded data onto a well-defined 1D waveguide. While it is common practice to approach surge forecasting with depth-integrated ocean models, especially in the context of tropical cyclones (Veeramon et al. 2017), the ability of models to represent CTWs could have implications for Australian system development priorities. Pursuing the work of Hetzel et al. (2017) regarding the (in)adequacy of barotropic ocean models is of particular relevance to the Australian context where the trade-off between representing baroclinic dynamics, spatial resolution, and uncertainty is of practical importance.

Improved methods to develop the idea of waveguide coordinates are surely possible. Sensitivity of the results to waveguide path realization should be explored and potentially leveraged for specific outcomes. For instance, to define a coastline that highlights wind orientations of particular significance to driving sea level, extending the manner in which Tilburg and Garvine (2004) relate measured winds to measured sea level to derive a parametric anomaly forecast model.

Extension of the 1D approach to also sample model fields along cross-shore profiles (not just at coastal points) could offer insight into the representation of...
relevant dynamics. But the algorithm presented is unlikely to be suited to such an extension as it does not provide a conformal map. While the coordinate directions are orthogonal at the coast, the directions loss meaning with distance offshore to the extent that the profiles can intersect.

Well-defined CTW coordinates could in principle facilitate the introduction of process specific numerical models like that of Brink and Chapman (1987) employed by Liao and Wang (2018a) into the operational setting. Accurate representation of certain ocean current features in particular could motivate this. However, a process-targeted model direction is at odds with the ongoing evolution of increasingly “concrete” generalized simulations (Petersen 2012) that are the mainstay of operational forecast centers, so the benefits of a dedicated CTW system would require extraordinary justification.

Forecasts at the coastal interface are both important and challenging. Evaluation approaches that isolate this domain can help align skill metrics with user significance. Although not pursued in this discussion, projection of candidate forecast system onto a common waveguide path will allow for detailed quantitative comparisons of propagation characteristics. Various signal processing techniques are available to exploit spatially ordered sets of time series data for propagation analysis, though the limitations of complex empirical orthogonal functions described by Merrifield and Guza (1990) should serve as a general caution about overinterpretation.

Finally we note that while forecasting systems will continue to be updated and extended, the data projection and presentation approaches demonstrated here are model independent and potentially employed as a generic capability within forecaster visual interface.

Acknowledgments. Thanks for input from Kevin Walsh at the University of Melbourne and James Chittleborough at the Bureau Tidal Unit. Real-time observational data shared with the Bureau were especially useful from Manly coasts-waterways/beach/storm-sites). Land and Water (https://www.qld.gov.au/environment/Queensland Government Department of Environment, generic capability within forecaster visual interface. Are model independent and potentially employed as a
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REFERENCES


