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# Expert elicitation of directional metocean parameters

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ABSTRACT

Probability distributions that describe metocean conditions are essential for design and operational decision making in offshore engineering. When data are insufficient to estimate these distributions an alternative is expert elicitation – a collection of techniques that translate personal qualitative knowledge into subjective probability distributions. We discuss elicitation of surface currents on the Exmouth Plateau, North-Western Australia, a region of intense oil and gas drilling and exploration. Metocean and offshore engineering experts agree that surface currents on the plateau exhibit large spatio-temporal variation, and that recorded observations do not fully capture this variability. Combining such experts' knowledge, we elicit the joint distribution of magnitude and direction by first focusing on the marginal distribution of direction, followed by the conditional distribution of magnitude given direction. Although we focus on surface currents, the direction/magnitude components are common to many metocean processes. The directional component complicates the problem by introducing circular probability distributions. The subjectivity of elicitation demands caution and transparency, and this is addressed by embedding our method into the established elicitation protocol, the Sheffield Elicitation Framework. The result is a general framework for eliciting metocean conditions when data are insufficient to estimate probabilistic summaries.

## 1. Introduction

Complex interactions between waves, winds and currents are central to design and operation decision making in offshore engineering. For example, metocean conditions are used for design risk assessments associated with extreme events (Jonathan and Ewans, 2013), to identify important relationships for condition maintenance (Xia, 2012), to estimate expected operation time windows (Chen et al., 2002), and to assess computational modelling of physical systems (Tahar and Kim, 2003). Since metocean conditions are inherently uncertain, probabilistic descriptions are necessary to formalise such design and decision issues (Bitner-Gregersen et al., 2014). Ideally, recorded observations would be available, but sometimes this is not the case, as when proceeding with design analyses for new exploration projects. In these situations, alternate sources of information must be harnessed, and the knowledge belonging to subject-matter experts is a natural choice.

The offshore engineering literature has reported on the use of expert knowledge and judgement to inform Bayesian networks for the risk assessment of shipping accidents (Afenyo et al., 2017; Hänninen, 2014; Hänninen et al., 2014; Zhang and Thai, 2016), utility curve construction in structural shipping design (Knight et al., 2015), and 'abandon ship' procedures (Akyuz, 2016). However, the above literature concentrates on point estimates and is not concerned with quantifying probability distributions that also describe the experts' uncertainty.

The process of translating experts' qualitative knowledge and uncertainties into subjective quantitative probability distributions is known in the literature as expert elicitation (Cooke, 1991; Meyer and Booker, 1981). It normally involves the interaction of a facilitator knowledgeable in uncertainty, probability and statistics and domain specific experts (O'Hagan et al., 2006; Goossens et al., 2008). The interaction can be complex, often lasting days, until both the facilitator and experts are content with the outcome (Garthwaite et al., 2005). In short, the role of the facilitator is to (a) extract knowledge from the experts in the form of probabilistic judgements and (b) fit probability distributions to their judgements.

Experts are often untrained in probabilistic reasoning, impelling the facilitator to pose questions in terms of basic statistical summaries such as ranges and quantiles, as opposed to more obscure summaries such as

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variances and expected values. The potential of loose vocabulary to distort results is real and when experts gather as a group, social dynamics come into play (O'Hagan et al., 2006). More subtle problems stem from cognitive heuristics and biases when individuals estimate probabilities (for a review see Kynn (2008)).

Expert elicitation researchers have provided protocols to optimise the elicitation process and stress the need for transparent documentation of the interactions between the facilitator and experts that led to the results. The current state of affairs is that, when carefully prosecuted, elicitation can be a very powerful tool. Evidence of this claim can be found in the publications, across many disciplines, that usefully employ elicitation. It has found its way into reliability engineering (Ioannou et al., 2017), energy (Chan et al., 2011), meteorology (Johnson et al., 2015), agriculture (Krayer von Krauss et al., 2004), health (Batz et al., 2012), conservation biology (Runge et al., 2011), ecology (Murray et al., 2009), geology (Lark et al., 2015), decision making for public policy (Gosling et al., 2012) and climate science (Kennedy et al., 2008). O'Hagan et al. (2006) provides an excellent review of the many more applications prior to 2006. However, to the best of our knowledge, elicitation has not been applied to metocean quantities.

We elicit surface currents (defined here as up to 10 m below the mean water level) at the Exmouth Plateau, in North-Western Australia. The Exmouth Plateau is a region of intense oil and gas drilling and exploration where distributions of winds, waves and currents are vital as, for example, when characterising the input space to physical models such as vessel motions (Milne et al., 2016), side-by-side offloading (Zhao et al., 2014), and oceanographic studies (Rayson et al., 2011). Of these metocean conditions, surface currents have proved to be the most difficult to numerically model (Dhanak and Xiros, 2016) and to comprehensively measure because the Exmouth Plateau's large spatio-temporal variability necessitates an extensive and costly implementation of mooring monitors. High spatial variability implies many mooring monitors are required to yield representative data. High temporal variability over seasons and years necessitates lengthy measurement campaigns.

We gathered six metocoean and offshore engineering experts drawn from both industry and academia. The experts agreed that surface currents on the Exmouth Plateau exhibit large spatio-temporal variation, exacerbated by extreme local eddies, internal waves, cyclonic forcing, and multiple generative processes counteracting or reinforcing one another, but that recorded observations do not fully capture this variability. The elicitation workshop was conducted over two days at The University of Western Australia, facilitated by a statistician experienced in the elicitation process.

Similar to wind and waves, surface currents are most commonly described in terms of magnitude (denoted by $\upsilon$) and direction (denoted by $\theta$). Although modelling Cartesian coordinates can be more straightforward statistically, the experts preferred discussing $\upsilon$ in meters per second, and $\theta$ as measured clockwise from North on $[0, 360)$. The article therefore elicits the joint probability of $\theta$ and $\upsilon$, $p(\theta, \upsilon)$. For reasons given in the article's main body, the experts were most comfortable with first discussing direction, followed by the magnitude associated with that direction. The problem was therefore decomposed into $p(\theta, \upsilon) = p(\theta)p(\upsilon|\theta)$. Marginalising over $\theta$ yields $p(\upsilon)$. On the advice of the experts, we elicited $p(\theta, \upsilon)$ for the Wet (November–April) and Dry (May–October) seasons separately.

For magnitude, the experts were asked to make plausible range and quantile judgements. This is known as the variable interval method, and is common practice in the elicitation literature (Garthwaite et al., 2005). We then fitted gamma and log-normal distributions to these judgements. Directional quantities have not yet been elicited in the literature and are more difficult because $\theta = 0$ and $\theta = 360$ are equivalent. We describe a variant of roulette elicitation (Gore, 1987), a graphical method whereby experts are asked to deposit chips into intervals to represent the probabilities of each interval's occurrence. Circular distributions are then required to fit the directional judgements. We allow for the possibility of the von Mises (Fisher, 1995), generalised von Mises (Gatto and Jammalamadaka, 2007) and asymmetric generalised von Mises (Kim and SenGupta, 2013) distributions. The final results are presented as the asymmetric generalised von Mises distribution.

The elicitation protocol described in this article follows the SHeffield Elicitation Framework (SHELF) (Gosling, 2018) and its accompanying software (Oakley and O'Hagan, 2010). SHELF has been successfully implemented in many other studies: for instance, Lark et al. (2015) and Ren and Oakley (2014). However, SHELF does not yet include circular distributions. In this paper, we present a general method to elicit distributions of directional quantities, where the joint distribution of the angle and the magnitude is desired, that can be used when quantitative characterisations of uncertain metocean inputs is required.

The article proceeds as follows. Section 2 provides a review of the surface currents at the Exmouth Plateau. Section 3 describes the design of the elicitation and workshop process, with an emphasis on how the directional component is elicited. Section 4 presents the elicitation results and distributional fits, and Section 5 offers the conclusions from this research.

## 2. The Exmouth Plateau

The Exmouth Plateau forms part of the North–West Shelf of Australia as shown in Fig. 1a. It is the second largest marginal plateau of offshore Australia with an area of 150000 $km^2$ located approximately 300 km offshore from North–Western Australia (Exon and Willcox, 1980). The water depth varies from 3500 m along its base, to 1500 m atop the plateau, and as shallow as 100 m on the Eastern shelf-slope (see Fig. 1b). It is one of the most economically significant maritime regions in Australia. Over 86 wells have been drilled since hydrocarbon exploration commenced in the late 1940s (NOPTA, 2017) and future activity is expected. The majority of the Floating Production Storage and Offloading (FPSO) facilities, which are utilised for much of the hydrocarbon production in the region, weathervane in response to the local meteorological and oceanic conditions. Critical to the design and safe operation of these facilities is an understanding of local surface current conditions and their variability.

On a global scale, the Exmouth Plateau is affected by the Leeuwin and Holloway currents. The Holloway Current originates North of the Exmouth Plateau from the Indonesian Throughflow, and flows southward to meet the head of Leeuwin Current at the Exmouth Plateau region (D'Adamo et al., 2009). In this region the global currents predominately flow towards the South–West, however seasonal flow reversals are common (Holloway and Nye, 1985). Localised temporal variation at the Exmouth Plateau stems from multiple sources. Semi-diurnal tidal currents govern short term variability (Holloway, 1988). Mid-term variability comes from the Wet/Dry seasonal effects of meteorological conditions such as winds, waves and tropical cyclones (Condie and Andrewartha, 2008). Climate drivers such as El Nino/La Niña cycles inject long term variability (Feng et al., 2003). The natural spatial variation is complicated by steep regional bathymetry. Internal waves are generated resulting from the interaction of the shelf slope and the barotropic tidal currents (Van Gastel et al., 2009), and extreme localised eddies can persist for several days (Morrow et al., 2003).

To install, maintain and record data from a single mooring monitor on the Exmouth Plateau for a year will cost in the order of hundreds of thousands of dollars. This factor coupled with the size of the Exmouth Plateau means that comprehensively observing the spatio-temporal variability the region's surface currents is difficult. However, some observational and modelling studies have been conducted in attempt to capture surface current behaviour on the Exmouth Plateau and in surrounding regions. As these studies inevitably inform our experts' opinions, some of these results are now discussed.

Indications of the magnitudes of the contributions of the global currents in the region can be inferred from measurements by Lowe et al. (2012). Two moorings were deployed on the 50 m and 100 m isobaths at