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Research

Drawing on diverse knowledge systems to enhance local climate understanding in the southern Cape, South Africa

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ABSTRACT. By overlaying terrestrial and marine perspectives, we examine complex system change at the local scale of the southern Cape and Agulhas Bank in South Africa through placing different knowledge bases on climate variability alongside each other. This research adds insights into how social components of complex systems interact with environmental change and contributes to confirming environmental regime shifts in the research area; identifying knowledge disconnects for ecosystem services linked to terrestrial water availability; and highlights scale disconnects in fisher observations in near- and off-shore change. The benefits of examining these diverse bodies of knowledge in parallel across terrestrial and marine systems are evident in the synergies and disconnects that emerge from our integrative approach. Although impossible to eliminate uncertainty around projected climate variability and change, this multi-evidence base strengthens advice for evidence-based, strategic decision making that is locally relevant. The methodology pursued adds to the global learning on overlaying multiple bodies of knowledge in support of sustainability.

Key Words: *Agulhas Bank; Benguela; climate variability; knowledge systems; marine; social-ecological systems; terrestrial*

INTRODUCTION

Uncertainties exist when examining global environmental changes at localized scales and different systems have numerous reactions to multiple stressors that play out over varying temporal and spatial scales (Walker et al. 2004). Because large-scale environmental change is becoming more evident, conventional ecological research is not necessarily conducted at a fast enough pace nor covers a large enough area to fully grasp these complex changes (Brook and McLachlan 2008, Biggs et al. 2009). Social-ecological systems are complex and operate across multiple scales, making it important to examine these systems by drawing on diverse perspectives (Ommer et al. 2012, Tengö et al. 2014). Local knowledge can be coupled with scientific data and research to make understanding of an issue more robust (Haggan et al. 2006, Lutz and Neis 2008, Marin 2010), thus contributing to more grounded knowledge for adaptive management practices in society (Ommer 2007, Tengö et al. 2014).

Multiple knowledge systems are many-faceted and can match or contrast with each other at different scales (Ommer 2007, Scholes et al. 2013). The triangulation of information is important for revealing potential mismatches or disagreements between knowledge streams, particularly when addressing knowledge gaps at different scales or to generate new insights (Tengö et al. 2014). Diverse knowledge types and their systems (ranging from local, place-based values to external research or policy information) are important for managing human activities in complex systems in a sustainable manner (Sterling et al. 2017). Managing for sustainability within social-ecological systems is further complicated by numerous stressors, such as climate variability and change, that induce additional responses and feedbacks.

Climate variability and associated changes, therefore, need to be contextualized as these changes are far from uniform spatially and differ across temporal scales. The juxtaposition of marine and terrestrial areas presents a particularly challenging context in this respect (Fang et al. 2018), with global and local manifestation of change evolving quite distinctly but in close proximity. Downscaling or translation of the impacts of change for land and sea systems is generally done in isolation, for example in the Intergovernmental Panel on Climate Change (IPCC) special reports on the Ocean and Cryosphere (IPCC 2019a) and on Climate change and Land (IPCC 2019b), making the exploration of the relationship between local terrestrial and marine drivers of variability and change difficult, but crucial. The extent to which these systems interact in their influence on human livelihoods has not been extensively researched, highlighting the importance of improving land-sea knowledge bases (e.g., Ramesh et al. 2015).

The "new normal" of variability in local climate (Wolski 2017) has ushered in an era of change for South African communities co-dependent on natural resources across the marine and terrestrial realms, providing an important window into perceptions and responses to interactions between terrestrial and marine systems under a changing climate. Considering factors that drive decisions around land-use practices or fishing methods synergistically are important to better understand how farmers or fishers of the same region operate in relation to environmental change (Thomas et al. 2007). Perceptions of risk that include environmental, social, economic, and political drivers are important because this may affect people's perceived or actual ability to respond (Grothmann and Patt 2005).

Situated in complex social-ecological environments of South Africa, our research explored how drawing on diverse knowledge systems could enhance local climate understanding and bridge land and sea perspectives. Using a parallel approach, we carried out qualitative and quantitative research that drew on diverse knowledge systems to improve local climate understanding through asking the following broad questions: "Are local knowledge of climate variability (i.e., weather patterns) by farmers and fishers in agreement and how do these compare to

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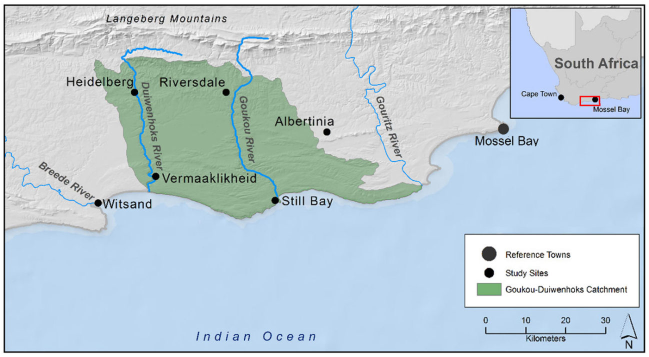
scientific observations, and are there synergies or mismatches across local and scientific knowledge strands examined?" "How are farmers responding to change within the context of climate variability compared to fishers in the southern Cape?" Last, we discuss the value of these findings in view of observed and future adaptations to change.

RESEARCH AREA

We examined links between terrestrial and marine social-ecological systems under the common theme of climate variability, at the local scale of South Africa's southern Cape and Agulhas Bank (Fig. 1). Our selected research area was bounded by the Langeberg Mountains to the north and the Indian Ocean to the south, creating confined micro-climate conditions for the water catchment areas of the Duiwenhoks and Goukou rivers on the seaward side of the bordering mountain range. The terrestrial component of our research area spanned the agricultural area between the towns of Witsand, Heidelberg, Riversdale, Albertinia, and Still Bay. The Duiwenhoks and Goukou catchment areas were settled by early European farmers in the 1700s and current land use activities are dominated by forestry, dairy farming, and tourism. The area experienced increasing pressure from intensive farming practices over the decades, which, coupled with changing climatic conditions, have altered natural ecosystem functioning (Price 2006). Trends toward drier conditions along the southern coast regions have been detected, and analyses in the southwestern regions suggested that lowland areas are drying whereas mountain areas receive an increased rainfall over time (Midgley et al. 2005, MacKellar et al. 2014).

Fig. 1. Location of the research area at the local scale of South Africa's southern Cape and Agulhas Bank, highlighting prominent towns and features mentioned in the text.



The marine component of our research area, part of the Benguela Current Large Marine Ecosystem (BCLME), represented the fishing grounds of the small-scale commercial linefishery operating in the inshore section of the central Agulhas Bank between Witsand and Mossel Bay (Gammage et al. 2017a). This linefishery has operated for over 100 years (Duggan et al. 2014, Visser 2015) and presently forms a boat-based, labor-intensive, and low-earning sector with an important human livelihood dimension. This handline fishery predominately targeted Silver kob (*Argyrosomus inodorus*) as these fish were regarded the most commercially viable. In the past, Cape hake (*Merluccius capensis*) were also present in this area but this species had not been caught recently (Gammage et al. 2017a).

The marine component also extended to the offshore Agulhas Bank, together forming the south coast/Agulhas bank subsystem of the southern Benguela (Hutchings et al. 2009, Jarre et al. 2015). Two major marine ecosystem regime shifts in the southern Benguela were identified by Howard et al. (2007): the first was mainly attributed to overfishing in the early 1960s with some environmental influence. The second regime shift occurred from the mid-1990s to early 2000s, primarily because of environmental shifts (Howard et al. 2007), but aggravated by fishing (Coetzee et al. 2008, Blamey et al. 2012). At the local scale of the southern Cape, knowledge gaps in the marine system were highlighted through research conducted by the Southern Cape Interdisciplinary Fisheries Research (SCIFR) project (Jarre et al. 2018). Scientific data sets for the Agulhas Bank have larger discrepancies compared to the west coast subsystem of the southern Benguela, resulting in limited understanding on how environmental changes are playing out (Hutchings et al. 2009, Lamont et al. 2018). However, there are warning signals associated with possible shifts on the Agulhas Bank such as increased inter-annual variability and biotic changes (Blamey et al. 2015, Watermeyer et al. 2016).

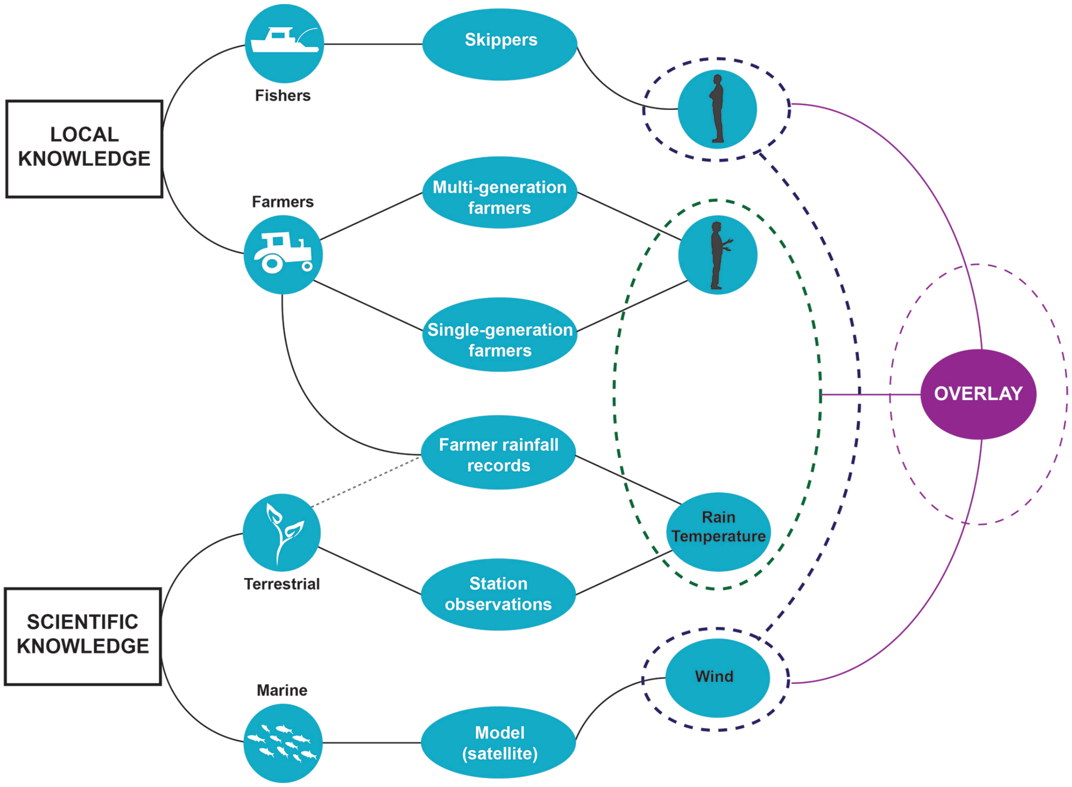
METHODS

Drawing on Tengö et al. (2014), our research used a parallel approach to bring together local climate knowledge from multiple sources, namely farmers, fishers, and scientists. Building on existing work done by the SCIFR team, the knowledge of selected natural resource users as knowledgeable experts of their social-ecological systems was placed alongside information derived from scientific data. Our research drew on work carried out by the SCIFR project on small-scale commercial linefishery communities in the southern Cape, including ethnographic research with skippers by Duggan (2012) and geographic research on multiple stressors in this coastal fishery (including climate variability) by Gammage et al. (2017a, b). Our interdisciplinary, two-fold approach examined local knowledge systems in concert with analysis of regional climate data, with the aim to build a more comprehensive understanding of complex terrestrial and marine social-ecological systems of the southern Cape (Fig. 2).

Local knowledge was examined through farmers and fishers based in our southern Cape research area by focusing on local perceptions of climate variability. Scientific knowledge was assessed by drawing on local weather station observations, in tandem with rainfall recordings from farmers, and model outputs based on satellite and other observations. We used a mixed methods approach within a convergent parallel design (see Creswell and Plano Clark 2011) to analyze different strands of qualitative and quantitative data, creating a multi-evidence base (e.g., Tengö et al. 2014) from diverse knowledge of farmers, fishers, and scientific observations under the common theme of climate variability. Quantitative and qualitative strands of data were collected during the same phase of the research process. Each strand was analyzed separately and then results were mixed during the overall interpretation to improve understanding of the topic and identify possible mismatches between data sets or different knowledge systems. Data collection and analyses per user group are detailed in Table 1.

Sampled natural resource users focused on farmers and fishers (specifically skippers) because they are the decision makers in

Fig. 2. Different strands of knowledge examined and how they are brought into dialogue for this research.



their respective farming or fishing activities. Understanding how these natural resource users respond to changes in their environment was examined by assessing how local practices have evolved over time. All farmers interviewed were Caucasian and most were native Afrikaans speakers. Of the 50 active farmers surveyed, 82% were commercial land users, 14% lifestyle land users, and 4% subsistence farmers (see Appendix 1). Most farmers were well educated (with a tertiary degree or diploma) and from a middle to upper-middle socioeconomic background. Fishers' observations were obtained from fieldwork carried out by Duggan (2012) and Gammage (2015) under the SCIFR project. This included 50 participants comprising skippers, boat owners, crew, members from associated industry, and spouses/partners. The fisher participants, who were all native Afrikaans speakers, represented a diverse range of backgrounds in terms of education levels, socioeconomic backgrounds, and Caucasian and Coloured heritages. Farmer and fisher typologies were comparable as the participants interviewed for our research and the SCIFR project had long-term experience within their respective agricultural or fishery sector, including multi-generational farmers or fishers, bringing a long-term outlook to climate variability changes.

RESULTS

Farmer and fisher local knowledge of climate variability

Local bodies of climate knowledge from farmers and fishers in our research area were location specific and included a mix of scientific and practical knowledge around agricultural and fishing activities, respectively. Types of climate knowledge were often contextualized from a multi-generational perspective for both farmers and fishers, where current generations drew on observations passed down through previous generations and evolved their knowledge bases accordingly.

Both terrestrial and marine climate systems of the southern Cape were deemed highly variable by farmers and fishers, where no definitive trends of change in the system were observed over time. Narratives that emerged from these local types of climate knowledge were nuanced and subtle changes were teased out over different temporal and spatial scales. Some fishers considered the multi-decadal variability of climate as a normal characteristic of the local marine environment, where different cycles of weather were repeated over time. However, these systems were thought to have increased in variability that exceeded the norm in recent memory. Similar to fisher observations, farmers emphasized the naturally variable nature of the local terrestrial environment but echoed that recent extreme events and subtle shifts in weather patterns appeared to be outside the expected norm.

Farmers were most invested in rainfall patterns and gave more detailed observations on possible rainfall changes over time (Appendix 2). Changes in extreme weather events (typically associated with intense rainfall events or prolonged dry periods) were one of the key observations made by farmers for the terrestrial environment. Later onset of seasonal autumn rainfall patterns in the current farming generation were also highlighted. Farmers were less certain of changes within temperature and wind regimes because these drivers were deemed highly variable over time and participants questioned the reliability of their memories

Table 1. Local climate knowledge from multiple sources brought into dialogue for this research (detailed methods are provided in Ward 2018).

User Group	Data Type	Data Collection	Analysis
Farmers	Qualitative	To obtain a diverse sample, six entrance points into local communities were used, as an attempt to talk to people from diverse backgrounds and a total of 50 farmers were interviewed. Unstructured interviews: free-ranging conversations arranged in advance to explore the climate variability aspect on a local level from different perspectives. Semi-structured interviews: an interview guide was made to cover pre-defined topics. Qualitative data were collected in two streams: first through unstructured interviews carried out during the scoping phase and second through semi-structured surveys in the subsequent phase of data collection. All data analyses were conducted using anonymity to protect respondents' identities. Farmers recommended to take part in the project were contacted through local forums or trusted key contacts and then a snowball sampling technique (Goodman 2011) was utilized to obtain a chain of referral details for other local farmers, who were subsequently contacted and, if consented, interviewed by the researcher.	Thematic analyses were used to identify specific trends or common themes with a focus on climate variability in terms of rainfall and temperature observations. Data from unstructured interviews and accounts gathered from key participants in the scoping phase were built into a narrative account (Newing 2011) to provide an overview of the research area in terms of farming practices and climate from local perspectives. These qualitative data were interrogated and summarized in a narrative manner, drawing on recordings from fieldwork notes by Ward (2018) and previous studies conducted in the study area by Mpfunzeni (2015) and Nzonda (2016) to add context. Structured observations and verbal data from the semi-structured interviews were recorded in the form of brief quotes and text summaries. These data were then combined with categorical and ratings information in Microsoft Excel® to create a database for analysis and comparison (Bazeley 2013). Content analysis was employed as a suitable technique for analyzing these texts and frequencies of words, phrases, and concepts were counted across this qualitative data set (Newing 2011). These data were then analyzed by means of thematic analyses to identify specific trends or common themes with a focus on climate variability in terms of rainfall and temperature observations. Climatic themes were then selected in terms of challenges experienced by farmers.
Fishers	Qualitative	Fishers' observations were obtained from fieldwork carried out by researchers of the Southern Cape Interdisciplinary Fisheries Research (SCIFR) project on the southern Cape handline fishery. Initial participant observation fieldwork was carried out between 2010 and 2011 by Duggan (2012) with a focus on commercial skippers from Still Bay and Melkhoutfontein. These skippers represented a diverse range of backgrounds, experience in their fishery, and multi-generational fishers. These fishers gave detailed accounts of their experiences and observations within the small-scale commercial handline fishery of the Southern Cape. In addition to participant observation, Duggan (2012) drew on semi-structured interviews carried out in terrestrial and marine working environments. Following this research, Gammage (2015) conducted research between 2013 and 2014 in six towns located on the southern Cape coastline: Mossel Bay, Gouritsmond, Melkhoutfontein, Still Bay, Vermaaklikheid, and Witsand. The sample size for this component of fieldwork was expanded to 50 participants comprising skippers, boat owners, crew, members from associated industry, and spouses/partners. Semi-structured interviews were used, as well as several group interviews of varying sizes. This research focused on multiple stressors to which fishers and fishing communities are exposed that play out over numerous temporal and spatial scales (see details in Gammage et al. 2017a, b).	Data were assessed initially in two separate streams, namely fisher observations and wind data, and results discussed in a comparative manner after initial analyses. Data were examined at annual and monthly scales so that it was comparable to terrestrial data analyses. Data analyses were guided by a number of research questions formulated to examine climate variability observed by fishers from the SCIFR research project, with a specific focus on coastal wind patterns. Fisher observations from Duggan (2012), Gammage (2015), and Gammage et al. (2017a, b) were collated and summarized with a focus on climate change and variability using a thematic approach. Key information distilled in summary format to analyze fisher knowledge were extracted from detailed ethnography and interviews. A focus was placed on fisher observations from skippers for comparative purposes to bridge farmer dialogue to fishers, because farmers interviewed were decision makers in terms of what and how they farm, making skippers comparable because they were primary decision makers for fishing activities. Observations from fishers other than skippers were included when examining more refined topics, such as direct questions to crew concerning how they perceive changes in wind patterns for the area.
Terrestrial	Quantitative	Data were collected using two sources: local farmer weather records and scientific observation stations. Of the 50 farmers interviewed, 13 shared complete rainfall records. Official terrestrial weather data were obtained from 10 scientific observation stations in the research area from the South African Weather Service, Agricultural Research Council (Western Cape Department of Agriculture), and Riversdale Co-operation (agriculture); these data sources included rainfall and temperature records. All rainfall and temperature data were coded accordingly and summarized according to their attributes based on time period and location, where data were analyzed at monthly and annual scales to minimize potential problems associated with accumulation of daily rainfall only recorded after a few days. Only complete, sequential time series were considered and therefore only two temperature time series (one coastal, one inland) were analyzed.	Rainfall data were interrogated using correlations between datasets to test for similarities or differences between multiple datasets at annual scale (see Appendix 3). Spearman's rank correlation and Kruskal-Wallis, Wilcoxon, or Welch two-sample t-tests (based on Shapiro-Wilkinson tests for difference from normality) were used through a combination of R packages and SPSS. Rainfall data were divided into time periods to examine any possible changes in climate variability. Data were then tested for significance according to locality and/or time period using a two-tailed two proportion z-test with equal variances. The time periods were determined according to farmer observations and work done by Blamey et al. (2012) on (marine) regime shifts in the southern Benguela. To encompass as much of the data as possible, four time periods were determined: **Period 1**: Before 1981 (based on farmers' observations of weather pattern shifts) **Period 2**: 1982 to 1995 (Blamey et al. 2012 noted wind shifts in the southern Benguela mid-1990s) **Period 3**: 1996 to 2007 (Blamey et al. 2012 noted wind shifts in the southern Benguela in the 2000s) **Period 4**: 2008 to 2015 Temperature time series were interrogated using sequential regime shift detection software (refer to https://www.beringclimate.noaa.gov/) to examine possible regime shifts (see Appendix 4). This method was chosen because of its ability to automatically detect statistically significant shifts in the mean level and the magnitude of fluctuations in time series, along with its ability to detect regime shifts toward the end of a time series and process time series with multiple shifts (Rodionov and Overland 2005, Howard et al. 2007, Blamey et al. 2012). Building on work carried out by Howard et al. (2007) and Blamey et al. (2012) and for comparative reasons, the cut-off length (l) of 10 was chosen to examine possible regime shifts as they are known to be associated with decadal-scale oceanic variability.

(con'd)

Marine	Quantitative	Data were obtained from two wind data products derived from NCEP-DOE Reanalysis 2 (https://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis2.html) and a blended wind product based on scatterometer retrievals. The first wind data product, NCEP-DOE Reanalysis 2 (Kanamitsu et al. 2002) referred to as NCEP-DOE, was found by Lamont et al. (2018) to be suitable for assessing shelf-scale upwelling variability in the southern Benguela and these data were representative of offshore wind patterns. The second wind data product utilized was a multi-year wind product created by Desbiolles et al. (2017), which retrieves scatterometer data from 1992 to present from four separate missions: ERS-1, ERS-2, QuikSCAT, and ASCAT. This blended wind product was suitable for examining air-sea interactions at climate mesoscale.	Initially, NCEP-DOE (1979 to 2015) and aggregate scatterometer (1993 to 2016) data points were tested for similarities or differences using Spearman's rank correlation tests and linear regression. When examining "extreme" wind days, wind speeds of 10 m/s or above were selected from scatterometer datasets because this is too strong for fishers to successfully go to sea. These days were then counted per month and compared on a seasonal basis using linear regression at both 5% (to identify significant trends) and 10% (to identify meaningful tendencies) significant levels. NCEP-DOE and scatterometer wind data for components U and V were then assessed using sequential regime shift detection software to examine possible regime shifts for both the mean and variability of the time series (see Appendix 5).

concerning observations or perceptions of change. Fishers discussed wind variability as a key environmental change experienced within their marine environments (Gammage et al. 2017a, b). Changes in prevailing wind patterns were subtle and varied, mirroring the complexity of the local marine system, where narratives around change focused on increased variability in intra-seasonal wind patterns. Fishers also attributed a recent decline of suitable sea days to persisting unfavorable weather conditions, highlighting changes in wind patterns as a key contributing variable.

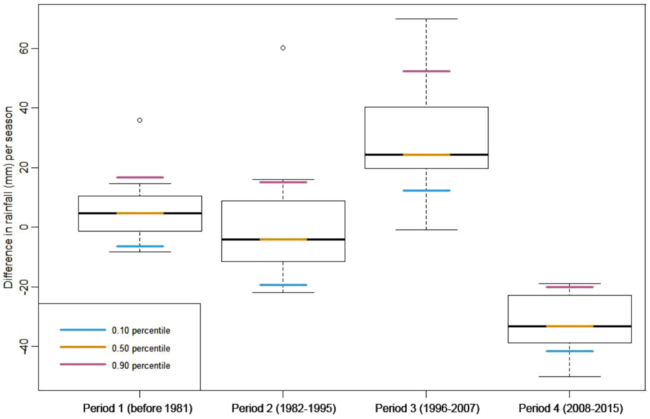
Linking local climate narratives to weather analyses

In agreement with farmers' and fishers' observations of the highly variable climate system of the southern Cape; analyses across (terrestrial) rainfall, (terrestrial) temperature, and (marine) wind datasets did not yield clear-cut trends of change over time, but rather decadal-scale variability.

Farmers' observations on rainfall changes were consistent with analyses of rainfall patterns over time. Since the 1980s, prolonged dry periods increased across our research area and an increase in extreme monthly rainfall events was detected in the eastern extent of the catchment areas. Complexity of local climate shifted across different spatial scales, matching farmers' observations that changes in local weather patterns were not necessarily a uniform experience. Micro-climates were highlighted as important factors when determining suitable farming activities to match fine-scale environmental conditions (Appendix 3).

For example, crop farmers observed that instead of planting in February or March like their predecessors, they planted in April or May. Monthly rainfall data were used to examine whether seasonality patterns had changed over the four time periods described in Table 1: Period 1 (before 1981); Period 2 (1982–1995); Period 3 (1996–2007) and Period 4 (2008–2015). Data were compared in terms of average differences between the cumulative "Old Season" (March, April, May) and "New Season" (April, May, June) against the four time periods for each farm and station. As illustrated in Figure 3, farmer observations around recent shifts in the onset of the traditional autumn rainfall season agreed with data analyses that indicated this shift (i.e., onset of rainfall occurring a month later) took place across our research area from the 2000s to present. These results also agreed with work by du Plessis and Schloms (2017), where rainfall data indicated a possible shift of the rainfall season's onset by a month (from March to April) for the larger south coast region.

Fig. 3. Differences in rainfall between Old and New Seasons across the research area (see Box A3.1 in Appendix 3). Positive difference indicates more rainfall in Old Season (March–May) and negative difference indicates more rainfall in New Season (April–June) during each period. Boxes indicate 25 and 75 percentiles, whiskers 5 and 95 percentiles. Differences are highly significant between P2, P3, and P4 ($p < 0.01$). Note pronounced variability in P3 and shift to more rainfall in the New Season in P4, after 2008.

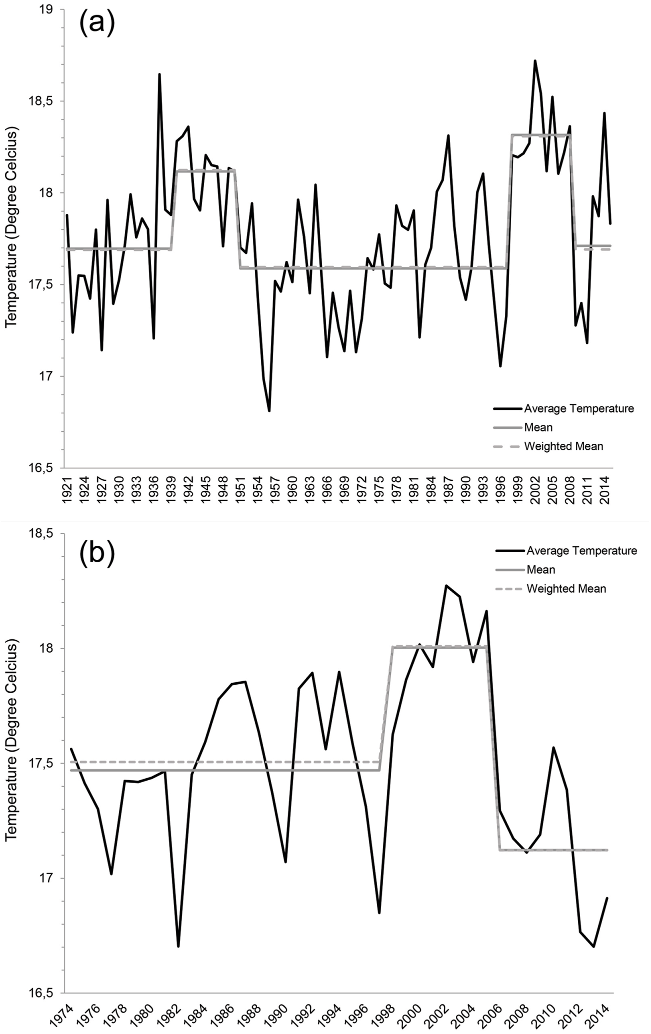


Although temperature analyses were limited in terms of data availability, data quality, and high variability, a shift was detected in the 1990s toward a warmer regime, which changed to a cooler period in the mid- to late-2000s (Fig. 4). Details for seasonal analyses are provided in Appendix 4. Farmers' narratives associated the 1990s with dry years, in line with warmer temperature tendencies overlapping with this period. The 1990s saw a shift of farming practices away from conventional plough methods toward conservation agriculture that improved soil moisture retention. This was partly attributed to these prolonged dry periods, coupled with economic considerations for improving agricultural outputs. Shifts in terrestrial temperatures for the southern Cape were linked to larger-scale changes in the southern Benguela system.

Marine environmental shifts, such changes in the magnitude and variability of upwelling, occurred in the south coast region of the Agulhas Bank in the mid-1990s and mid- to late-2000s (Blamey et al. 2012, Blamey et al. 2015, Lamont et al. 2018), which was comparable to analyzed terrestrial temperature shifts (Appendix

4). Additionally, analyzed wind data also indicated regime shifts in the mid-1990s toward an increasing easterly wind pattern, and again in the mid-2000s indicating a further dominance of easterly winds, corresponding to time frames from existing scientific work and analyzed temperature shifts described above (Appendix 4).

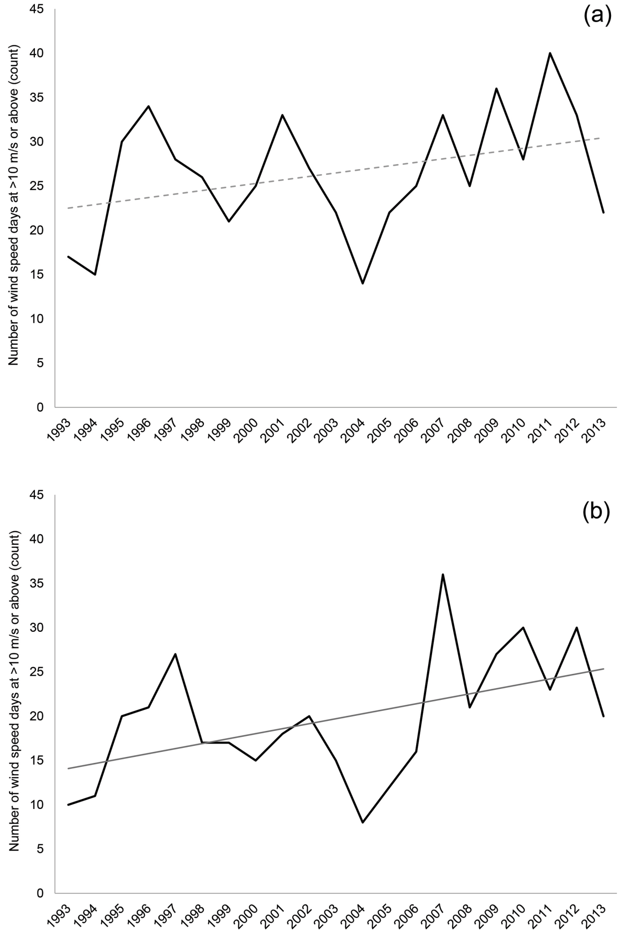
Fig. 4. Average annual temperature (running from June to May) with regime shifts for (a) Mossel Bay, representative of coastal conditions, and (b) Riversdale, representative of inland conditions in the study area.



Fishers' narratives on changes in wind patterns for the south coast focused on changes in intra-seasonal patterns, referencing a noticeable change in the late 2000s, where prevailing wind directions across different seasons shifted to persistent southeasterlies. These observations agreed with wind data analyses (see Appendix 5). Wind data also indicated possible shifts toward the end of the time series (after 2010, because most series ended in 2014), but this requires further investigation before interpretation because time series methods are less reliable toward the end of the time series in question (Blamey et al. 2012). Definitive shifts based on wind data were identified in the mid-1990s and again in 2007, which match local climate knowledge (fishers' narratives) and other scientific knowledge (Blamey et al. 2015, Lamont et al. 2018) for the wider research area.

Fishers' observations of increased extreme wind days did not match the analyses of near-shore wind products, which did not yield any discernible trends of change over time for extreme wind days. However, off-shore drivers showed a clear tendency toward increased number of days with stronger winds over time at shelf scale (Fig. 5). Along with findings of increased wave height (Lyttle et al. 2021), possibly influenced by off-shore wind and swell (Hanley et al. 2010), an increased tendency of extreme wind days at shelf scale suggested that fishers' observations of deteriorating conditions suitable for them to go to sea (particularly in austral summer during fishing season) matched at off-shore rather than near-shore scale in scientific data. Fishers' observations of increased variability were only reflected in annual time series of wind data products, notably where increased variability over time in east/west wind components were found at both off- and near-shore points (Appendix 5).

Fig. 5. Number of extreme wind days (> 10 m/s) for austral summer months, at the (a) aggregate scatterometer data point where the upward tendency was not significant at either 5% or 10% significance levels, and at the (b) NCEP-DOE data point, where the upward tendency was significant (p = 0.029).



Linking terrestrial and marine narratives

A common thread linking farmer and fisher narratives was distilled from accounts on broader environmental interactions between land and sea, as described by some participants. One such account from the fishing community linked rainfall and fish availability, weaving complex narratives around historical experience that hypothesized good fish catches were related to poor terrestrial rainfall years, whereas good rainfall years could result in poor catches. This narrative translated into a fisher folklore stating if the farmers were "happy" (i.e., good rainfall, which meant a profitable agricultural year), the fishers were "sad" (i.e., poor fish catches that equated to economic losses in the fishery sector) and vice versa. Qualifying this statement was problematic because it was unclear whether this narrative referred to the larger interplay of the environmental system between local sea conditions and related weather patterns, or more point specific impacts of river systems that run into the sea. Although the altering of river systems through agricultural impacts (e.g., chemical inputs and degradation of wetland systems) and freshwater flow (e.g., more fresh water entering the sea during flood events and less during drought events) could impact local fish abundance (Acker et al. 2005, Auricht et al. 2017), farmers clearly linked the relationship between land and sea to a larger interplay of environmental factors.

Multi-generational farmers linked rainfall patterns to sea temperatures and described similar theories on how this larger system interplays. Referencing weather patterns on a temporal scale that stretched up to 75 years ago through drawing on multiple generations of experience, these farmers relayed that warmer sea temperatures at the beginning of the calendar year generally foretold a good rain season over the mid-year period for farmers. The reverse was narrated for colder sea temperatures, which entailed poor rains in our research area. When referring to ethnography from a skipper regarding the interconnected nature of the natural marine and terrestrial systems, rainfall time series from farmers showed that 1969 as a particularly low rainfall year, in line with the skipper's observation.

Although 1969 was not the lowest recorded rainfall year, which raises issues in relation to distortion of knowledge through shifting baselines (Pauly 1995), individuals tend to remember extreme weather events more clearly, a natural reflection of human perception and memory (Osbahr et al. 2011). The high availability of silver kob observed by this skipper during this associated drought year could be linked to numerous possibilities, ranging from fishing effort to climatic conditions. Currie et al. (2020) noted that kob species abundances on the Agulhas Bank had already declined substantially from the 1930s and inshore trawl landings of silver kob decreased considerably between the mid-1960s and early 1980s, possibly reflecting the long-term decline of this fish species in the area. However, decreased inshore trawl effort from the mid-1960s may have allowed handline skippers of the southern Cape to land more silver kob because of decreased competition from trawling.

Alternatively, 1969 to 1970 was a weak El Niño period, where El Niño events are typically associated with less prevalent southerly winds in the southern Benguela system (Field and Shillington 2005). This El Niño event over the traditional summer fishing season of 1969–1970 could have resulted in unusually calm conditions and thus skippers in the southern Cape may have increased fishing effort because of plentiful sea days. El Niño-Southern Oscillation (ENSO) primarily influences summer rainfall patterns in southern Africa (Dieppois et al. 2015), while variability of winter southern African rainfall is related to the Southern Annular Mode (SAM) that also impacts on South Atlantic sea surface temperature (Reason and Rouault 2005). However, positive influence of ENSO on winter rainfall areas of South Africa has been noted, where more frequent dry spells are associated with El Niño events (Philippon et al. 2012). It should be cautioned that southern coastal regions, such as the southern Cape, have a more complex relationship with ENSO signals because this aseasonal rainfall area is affected by climate processes driving both summer and winter rainfall variability (Dieppois et al. 2016).

Farmers linked terrestrial to marine systems through fish catches because they spent their austral summer vacation period on the coast engaged in recreational fishing activities. Because of the scenic location of Still Bay, farming families camped there and fished off the beach, a custom that was well established by the 1860s (Visser 2015). Farmers hypothesized if they caught silver kob in Still Bay, this indicated warmer sea temperatures because these fish species were perceived to take the bait more readily in these conditions, pre-empting a good rainfall season for the farmers. Conversely, if farmers caught hake, this indicated cold sea water because these fish were perceived to bite during colder conditions, hence anticipating a poor rainfall year. Through overlaying fisher and farmer observations we investigated this narrative. For example, Still Bay skippers noted an influx of hake in their fishing grounds in the late 1990s because of colder inshore waters favored by this species (Duggan 2012) and farmers associated the 1990s as a relatively dry period compared to past memory.

Although this rainfall prediction was deemed reliable in previous farming generations, current farming generations observed that this relationship was not as clear as in the past, also noted by Thomas et al. (2007). Some farmers speculated that the winter rainfall regime had changed over time and typical wind patterns associated with winter rainfall from cold fronts had altered in recent memory. Although it is possible that fewer low pressure systems reached our research area in winter, gaps in understanding persist because of the complex nature of interacting large-scale atmospheric pressure fields (Allsopp et al. 2014). The South Atlantic High Pressure System (or South Atlantic Anticyclone) is responsible for the dominant wind system over the southern Atlantic Ocean, and work synthesized by Jarre et al. (2015) indicated that this system shifted in a southerly direction from the 1980s to 2000s, after which it shifted back northwards. This shift was linked to increased south or south-easterly winds in the 1990s across the southern Benguela (Blamey et al. 2015, Jarre et al. 2015). Farmers in the southern Cape associated the 1990s with a particularly dry period, which was further reflected in a clear warm period from terrestrial temperature data analyses during this period. The 1990s are also overlaid with decreasing off-shore westerly winds over summer periods (see Appendix 5), where corresponding increases in easterly winds were linked to increased upwelling, coupled with associated colder sea temperatures on the Agulhas Bank (Blamey et al. 2012, Lamont et al. 2018). This could be linked to the influx of hake in the Still Bay area along with colder waters in the late 1990s (Duggan 2012).

Responding to change

When examining responses in relation to climate variability, both farming and fishing communities in the research area did not place this stressor as the top concern.

Southern Cape farming communities

Substantial changes in the agricultural sector of the southern Cape took place in the recent past, altering the agricultural landscape and (more noticeably) the type of farmers. Although most farmers were engaged in large-scale commercial agriculture, there was a distinction between multi-generational farming families (present in the area for more than one generation) and first-generation farmers, who had moved into the area from the 1980s. Multi-generation farmers employed less diversified farming practices and focused on traditional sheep, grain, cattle and dairy production. These farmers used mixed farming strategies (for example altering livestock to grain ratio) to build resilience, depending on their individual access to technology, conservation practices, market demands, and (more minor) climate variability. First-generation farmers, while engaged primary in commercially viable agriculture associated with dairy, sheep, and cattle, also diversified into "niche" markets such as game meat, berries, and avocado to strengthen livelihood income strategies. These large-scale commercial farmers could be considered resilient in that they employed numerous farming strategies and altered them according to market, technology, and climate considerations. However, a large amount of financial capital was required to support this livelihood strategy, which could result in these farmers reaching their adaptive capacity limit if future climate becomes even more variable (Wiid and Ziervogel 2012).

From the 1980s, the most noticeable change in the southern Cape was the decline of the dairy industry. Agricultural practices shifted from dairy-dominated activities to grain, sheep, and ostrich farming because of unfavorable market forces. This also saw a marked decline of small- and medium-scale dairy farmers across the area, where 96% of these farms ceased to exist by local estimates. The decline of small- and medium-scale farmers was largely due to reactive strategies, where unfavorable market forces, compounded by harsh dry spells experienced in the 1990s, pushed vulnerable farmers into leaving the agriculture sector. The remaining subsistence farmers were more vulnerable to change compared to their large-scale commercial counterparts. These small-scale farmers were unable to derive a viable income through farming activities alone and tended to diversify their livelihood strategies outside of the agricultural sector. This change was linked to the narrative of "scale of economy," where farmers whose primary livelihood was agriculture noted that it is not feasible to successfully compete in modern contexts as smallholders (e.g., Collier and Dercon 2014).

The decline of commercial small- and medium-scale farmers in the southern Cape also saw the introduction of a new type of land use, namely "lifestyle" farming, where the landowner does not derive primary income from agricultural activities but is a producer of agricultural goods and impacts the physical landscape (Pinto-Correia et al. 2015). In Europe, lifestyle farming formed a socio-technological niche as it introduced novel land uses (Pinto-Correia et al. 2015). This was reflected in the southern Cape where lifestyle farmers introduced agricultural products such as olives, wine, and game that altered the traditional farming landscape. This relatively new form of farming also placed a focus on land practices linked to conservation (i.e., clearing of alien vegetation and rehabilitation of indigenous plants), where similar trends were observed in Australia (Gill et al. 2010, Pannell and Wilkinson 2009). Although lifestyle farmers were resilient because they had access to large amounts of financial capital to support their desired farming strategies, this shift in farming practices could also create vulnerabilities in the larger system. For example, the shift from labor-intensive dairy farming to mechanized crop production or lifestyle agriculture in the southern Cape affected the traditional farm workforce (Ward 2018). These shifts left farm workers more vulnerable because they had limited agency in terms of financial and social capital, coupled with burdens of health problems such as alcohol abuse (London 2003).

Southern Cape fishing communities

The commercial, small-scale handline fishery in the southern Cape has a history of marginalization as policy favored large-scale commercial trawl fisheries since the 20th century (Visser 2015). Additionally, these handline fisheries traditionally struggled to access markets, either because of the remoteness of geographic location or competition with commercial trawlers (Visser 2015). Recently, this fishery has not had a productive or lucrative fishing season because fishers have not been able to catch enough silver kob to make their livelihoods financially viable (Gammage et al. 2017b). Gammage et al. (2017b) found that southern Cape handline fishers responded to stressors either through adapting in the long term or waiting for the poor fishing conditions to improve by turning to reacting or coping strategies.

Fishers who employed long-term adaptive strategies, such as changing fishing craft and target fish species, were more resilient to change because they tended to have a more business-orientated approach and sufficient access to financing (Gammage et al. 2017b). This strategy aligned with large-scale commercial farmers in the southern Cape, who were able to respond to change by relying on financial capital. Although this perceived advantage made these farmers and fishers resilient, this resilience could be compromised if their adaptive capacity to meet financial challenges was exceeded. In contrast, fishers who employed coping or reacting strategies relied on supplementary livelihood strategies such as alternative informal employment, spousal income, and social grants. While waiting for poor fishing conditions to improve, these fishers either decreased fishing effort or targeted alternative (usually less lucrative) fish species (Gammage et al. 2017b).

DISCUSSION

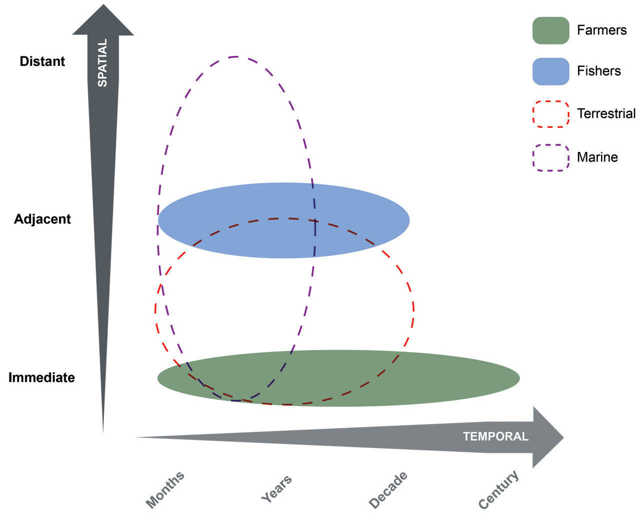
When placing different knowledge bases on climate variability alongside each other, there was nuanced parity between farmer, fisher, and scientific observations. The results showed (a) high location-specificity in terrestrial rainfall, but throughout (b) a shift in the onset of autumn rainfall from March to April; (c) decadal-scale changes in terrestrial temperatures, coinciding with (d) decadal-scale changes in winds at sea, and (e) indications of deteriorating ocean state. Historical local knowledge bridged land

and sea interplay through linking rainfall patterns to sea temperatures. Finally, both farmers and fishers did not place climate variability as their first concern. We now examine synergies and mismatches (including shifting baselines) and responses from farming and fishing communities to uncertainty. Finally, we discuss these findings in context of observed and future adaptations to change, in view of the improved knowledge on climate variability and change presented here.

Examining synergies and mismatches

In the southern Cape, local knowledge complemented and enhanced scientific knowledge, highlighting the importance of historical observations across generations of farmers and fishers. This deep-seated understanding of climate through generations of local experience provided valuable narratives on past patterns of local ecosystems, particularly where historical baseline information was not readily available (Fabricius et al. 2006, Tengö et al. 2014). Understanding change from the context of different knowledge bases helped identify mismatches between different understandings and highlighted the importance of scale-appropriate data when assessing possible environmental or climatic trends. Different knowledge strands were placed alongside and examined over varying temporal and spatial scales depending on data availability, as illustrated in Figure 6.

Fig. 6. Different knowledge strands, namely local knowledge of farming and fishing communities in the southern Cape and terrestrial and marine scientific data, examined over varying temporal and spatial scales. Spatial scale can be described as immediate (farm or specific location on the coast), adjacent (catchment or bay), and distant (southern Cape region or Agulhas Bank).



When looking at local climate knowledge for our research, farmers focused on their immediate surroundings (i.e., on their farm), which could stretch back 100 years in the case of some multi-generational farming families. Fishers' local climate knowledge focused on adjacent areas because their fishing grounds were in the inshore area of the Agulhas Bank, stretching back a few decades in the case of some fishing families. The terrestrial component examined through scientific data bases spanned immediate (i.e., farm) and adjacent (i.e., catchment areas) spatial scales, stretching back a few decades. The marine component ran from immediate (i.e., coastal) to adjacent (i.e., inshore Agulhas Bank) to distant (i.e., offshore Agulhas Bank) spatial scales, but datasets were mostly shorter than terrestrial datasets.

Social-ecological systems usually involve groups of resource users that are interlinked to each other and numerous resources across multiple scales. This is influenced by spatial and temporal changes within these complex systems (e.g., Janssen et al. 2007). Although types of local climate knowledge of farmers and fishers were difficult to compare on a spatial scale because there was no overlap, the temporal scale offered the opportunity to overlay terrestrial and marine perspectives of different time periods that described changes in environmental regimes. Those terrestrial and marine scientific datasets allowed synergies to emerge for periods of significant change in environmental regimes on both temporal and spatial scales.

Synergies through multiple dimensions of knowledge

Whereas traditional scientific research and existing policies tend to focus on larger scale climate trends at, for example, provincial or national levels (Ziervogel et al. 2014), our research illustrated the importance of contextualizing temporal and spatial changes in relation to local climate variability, in agreement with Marin (2010). Climate variability and associated changes need to be contextualized because these changes were not uniform across our terrestrial and marine research area and differed across temporal and spatial scales. This has considerable implications for farming and fishing communities reliant on natural resource bases because considering different strategies based on changing micro-climate characteristics will enhance the adaptive capacity of these users. Given the complexity of local systems in the context of global change, our results support the general recommendation that strategies for sustainability should take on many different forms because there is no "one size fits all" approach (Walker et al. 2004).

Overlaying multiple datasets and observations from numerous sources proved useful when grappling with the high uncertainties characteristic of complex systems. Tendencies observed in marine wind data patterns were overlaid with shifts detected from terrestrial temperature time series, thus strengthening the outlook for possible time periods of environmental regime shifts in our research area. Local fisher and farmer knowledge also overlapped when comparing time frames of possible environmental regime shifts. The complexity of the natural system of the southern Cape and Agulhas Bank was most evident in narratives around marine wind tendencies and terrestrial temperature patterns, where overlaying multiple knowledge dimensions was useful to build a more comprehensive understanding on possible climate shifts, in view of the high interannual variability.

Highlighted here is the importance of considering subtle changes in climate that are specific to a particular area within the broader context of climate variability at a national level, to better understand challenges presented to livelihoods at a local scale. Only considering climate criteria important to institutional decision-making processes, such as drought or flooding, may not be sufficient for natural resource users to succeed in the face of localized climate variability (Thomas et al. 2007). For example, farmers might underpin strategies on subtle climate variables such as the timing of the onset of rainfall associated with planting season, which are representative of real criteria that are locally relevant to resilient farming strategies. Through examining themes in relation to climate variability that were generated through perceptions of local farmers and fishers in the southern Cape, synergies between local and scientific knowledge bases added meaningful insights to local climate realities, in line with findings of Haggan et al. (2006), and Marin (2010).

Knowledge disconnects

Knowledge disconnects are important to understand in the context of sustainable management of human activities in a systems-based paradigm (Tengö et al. 2014). Conflicting data or contrasting views and values (e.g., Verran 2002), whether held by scientists, policy makers, or resource users, can undermine sustainable adaptation or transformation of local social-ecological systems. Miscommunication, misdirected resources, and policy failure can result from knowledge disconnects (Sterling et al. 2017). There are persisting knowledge gaps and poor understanding around environmental and climate variability in the southern Cape region and Agulhas Bank system, from local-scale drivers such as shifting rainfall patterns or localized marine upwelling, to large-scale processes linked to the interaction between the South Atlantic and South Indian Anticyclone. This poses challenges when dealing with high uncertainty in these complex social-ecological systems. Data-poor environments further hinder our ability to better manage anthropogenic impacts on these local systems or devise scale-appropriate policies that benefit people while protecting or enhancing ecosystem services.

Knowledge disconnects existed in the marine component of our research because of a lack of long-term, high quality monitoring environmental data, coupled with a naturally variable and complex climate system based on geographic location. For example, mismatches between fishers' knowledge and data analyses occurred when examining extreme wind days in the near-shore environment. Fishers observed that sea days had decreased over time partly because of unfavorable wind conditions, however these trends were not reflected in the available scientific data. Gammage et al. (2017a) discuss how the fishery operated in an unfavorable economic environment at the time, making it possible that weather was blamed for a decision largely based on resource scarcity and high input costs. However, these knowledge disconnects could also arise from scale mismatches, as changes in the off-shore environment showed a tendency of increased extreme wind days over time, corroborating fishers' observations at shelf scale but not necessarily in the in-shore environments where they mostly operated.

From the terrestrial perspective, an example of knowledge disconnects can be drawn from the complexities surrounding freshwater in the southern Cape, which play out within environmental, social, and political spheres for farmers. Knowledge disconnects were present between observed changing rainfall patterns, policy restrictions on allocation or storage from local river systems, and increasing agricultural demand. Many farmers expressed frustration with current water allocation policies, which were considered limiting and not in tune with changing weather patterns, such as increased intense rainfall events (i.e., freshwater floods straight into the sea in one event) and prolonged dry periods (i.e., policies limit storage of water on farms). Scientific data on changing rainfall patterns were highly varied across our research area, but an indication of increased dry months over time across two out of three catchment locations was detected (refer to Appendix 3). The disjointed nature of managing at the scale of watershed areas by local, provincial, and national government, in conjunction with highly variable local climate systems of the southern Cape, could lead to local resource users reaching the limit of their adaptive capacity if adaptation measures do not account for possible future climate shifts (Wiid and Ziervogel 2012).

Shifting baselines are also important to consider when examining knowledge disconnects (Pauly 1995) because the interpretation of present variability observed in natural resources (such as water availability or fish abundance) by natural resource users is dependent on historical knowledge of these resources (e.g., Sáenz-Arroyo et al. 2005, Papworth et al. 2009, Ainsworth et al. 2008). Together with high environmental and climatic variability, it was challenging to examine the extent to which fish stocks changed over time because of a lack of historical data. This could result in knowledge mismatches within fishers' observations of how and why fish stocks are altering over time (Gammage et al. 2017a). The substantial depletion of economically important fish stocks (such as *Argyrosomus* [kob] species) over the last century on the Agulhas Bank was the result of drivers ranging from fishing pressure to climate and environmental change dynamics (Currie et al. 2020). Consequently, consistent, large catches of large-sized kob species historically fished on the Central and Eastern Agulhas Bank are difficult to imagine for contemporary fishers and scientists. This illustrated the importance of historical data to counter shifting baselines, demonstrating how these fish communities have changed drastically since the 1900s. Shifting baselines are problematic in that human societies become tolerant to the creeping loss of biodiversity (Sáenz-Arroyo et al. 2005), which can undermine the sustainability of social-ecological systems (Folke et al. 2011).

Responding to uncertainty

All farmers stressed that weather patterns in the southern Cape were highly variable and not characterized by predictable trends, and thus were viewed as part of the agricultural environment. Farmers regarded the impact of weather patterns on farming strategies as either an adapting (medium-term) or coping (short-term) exercise. Similarly, fishers also highlighted that their local marine system was inherently variable in terms of weather patterns, where discrepancies emerged between different observations as to whether this variability was cyclic or had become more extreme over time (Gammage et al. 2017a). The unseasonal weather characteristics of the southern Cape could dampen changes that signal permanent shifts in climate patterns (Maddison 2007) and farmers who employed coping rather than adapting strategies may become more vulnerable over time (in line with Folke et al. 2011). Fishers faced a similar challenge in that the failure to correctly identify local climate drivers could hamper their ability to successfully respond to these stressors. This was reinforced by the lack of good quality, long-term environmental data and the naturally variable climate system of the Agulhas Bank.

This high uncertainty presented a major challenge in both farming and fishing communities for local climate adaptation, as knowledge disconnects were translated into perceptions of climate variability (e.g., Grothmann and Patt 2005) and thus responses by farmers and fishers may not be sufficient because of the complexities associated with the natural system. Farmers placed challenges associated with finances, politics, workforce, and water availability as more pressing than climate variability. In fishing communities, the long history of fishers' marginalization within the linefishery sector from a political stance (Visser 2015) resulted in fishers identifying policy and regulation as a major stressor over climate variability (Gammage et al. 2017b, Gammage and Jarre 2021). Both farmers and fishers viewed markets as hostile entities, where they felt they were competing against monopoly industries that were not well regulated.

Climate variability and the associated change exacerbated political and economic stressors, which were top of mind. A failure to recognize climate changes by local communities could push these natural resource users into vulnerable states should the natural system experience sudden changes or regime shifts. Although both farmers and fishers in the southern Cape did not place climate variability as the key stressor to which they planned for future adaptation, evolving practices such as conservation agriculture provided intricate narratives on climate-related adaption strategies taking place in our research area. Moving forward, effective decision making for adaption within these complex, multi-scalar social-ecological systems will require approaches that focus on increasing the capacity of stakeholders to make sustainable decisions within rapidly changing ecological, social, and political environments (Naess 2013). Scenario planning processes can provide opportunities for natural resource users to consider pathways for future responses to change, while simultaneously enhancing personal and local adaptive capacity, as demonstrated by Gammage and Jarre (2021). These tools integrate different knowledge streams, identifying ways to better address challenges across different scales in these complex systems, and provide an opportunity to build off the improved knowledge on climate variability and change presented here.

CONCLUSION

Our approaches placing farmer and fisher narratives alongside scientific observations were effective as each knowledge stream added value within an individual context and were equally valuable when used in parallel to examine complex systems. The individual context allowed our research to investigate climate variability observations of farmers and fishers to understand why individuals responded (or not) to system stressors. This was then built into scientific knowledge through interrogating databases by asking questions specific to climate experiences of local actors. Local and scientific knowledge bases were then placed alongside to better understand complex local systems under climate variability.

From a historical perspective, narratives from farmers and fishers in the southern Cape provided a multi-generational perspective of change that in turn created a rich backdrop to understanding how the agricultural and handline fishery sectors have evolved in this area. This also provided context for how climate variability was experienced over multiple decadal scales in the southern Cape, addressing complex knowledge disconnects caused by shifting baselines. Local knowledge on climate variability and change from farmers and fishers provided valuable insight into complex, multi-scale drivers of change that play out over different temporal and spatial time frames. Through further examining multiple dimensions of knowledge relating to environmental change in complex social-ecological systems and overlaying these bodies of knowledge, a nuanced understanding was obtained and confirmed that perceptions of climate variability play a critical role in determining the motivation of farming and fishing communities to respond to multiple stressors within complex social-ecological systems.

This contribution brings together two entities that are traditionally viewed in isolation: land and sea. Through integrating different bodies of knowledge from terrestrial and marine social-ecological systems of the southern Cape and Agulhas Bank, this work contributes a multi-evidence base of knowledge toward improving our understanding of local climate variability and change over time. We highlight the importance of interpreting pressing challenges of the Anthropocene within the context of local livelihood realities to better inform adaptation practices at different scales.

Responses to this article can be read online at:
https://www.ecologyandsociety.org/issues/responses.php/12712

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Data Availability:

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available because they contain information that could compromise the privacy of research participants.

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Appendix 1. Farmer Typologies and Agricultural Profile

Table A1.1: Typologies of active farmers who participated in semi-structured interviews.

	Farm size (hectares)	**Years on farm (average)†**	**Farming as income**	**Farming type**
‡**Commercial multi-generation** (large-scale)	Average: 1500 Max: 3500 Min: 180	27	Primary	More common: sheep (wool/meat), grain (e.g., canola, wheat, barley), cattle (beef), dairy (milk) Less common: ostrich, thatch, vegetables, lucerne, goats
‡**Commercial first-generation** (large-scale)	Average: 1375 Max: 3500 Min: 130	26	Primary	More common: dairy, sheep, cattle Less common: ostrich, buffalo (game), grain, avocado, berries, vegetables
Lifestyle (high-end, niche markets)	Average: 250 Max: 967 Min: 4	16	Secondary	More common: olives, vegetables, fruit Less common: sheep, cattle, honey, vineyards, thatch, game
Subsistence (small-scale)	Average: 33 Max: 54 Min: 12	31	Mixed	More common: chickens, ducks Less common: sheep, calf-rearing

† 'Years on farm' refers to number of years surveyed farmer has been actively farming on their farm specifically located in the research area.

‡ While both first and multi-generational farmer typologies have actively farmed for an average of 26/27 years, first-generation farmers are new to the area in the sense that they have no prior exposure to farming in the southern Cape. Most multi-generational farming families have been present in the area for three generations (i.e., from the 1940s). Approximately 30 % of multi-generational farming families have farmed in the area since the 1880s.

The 50 active farms surveyed fell into three ‘catchment’ areas, divided up into the Duiwenhoks/Breede, Goukou and Goukou/Gouritz (see Figure A1.1). From this sample, 68 % fell into the Goukou catchment area, 22 % in the Duiwenhoks/Breede and 10 % in the Goukou/Gouritz grouping. The research area was also divided into three distinctive areas: coastal (farms along the Indian Ocean coast which marks the southern boundary of the study area), vlakte (farms on the lowlands in the middle) and mountain (farms in the Langeberg Mountains). From the 50 active famers sampled, 54 % farmed on the vlakte areas, 24 % on the coast and 22 % in the mountainous areas.

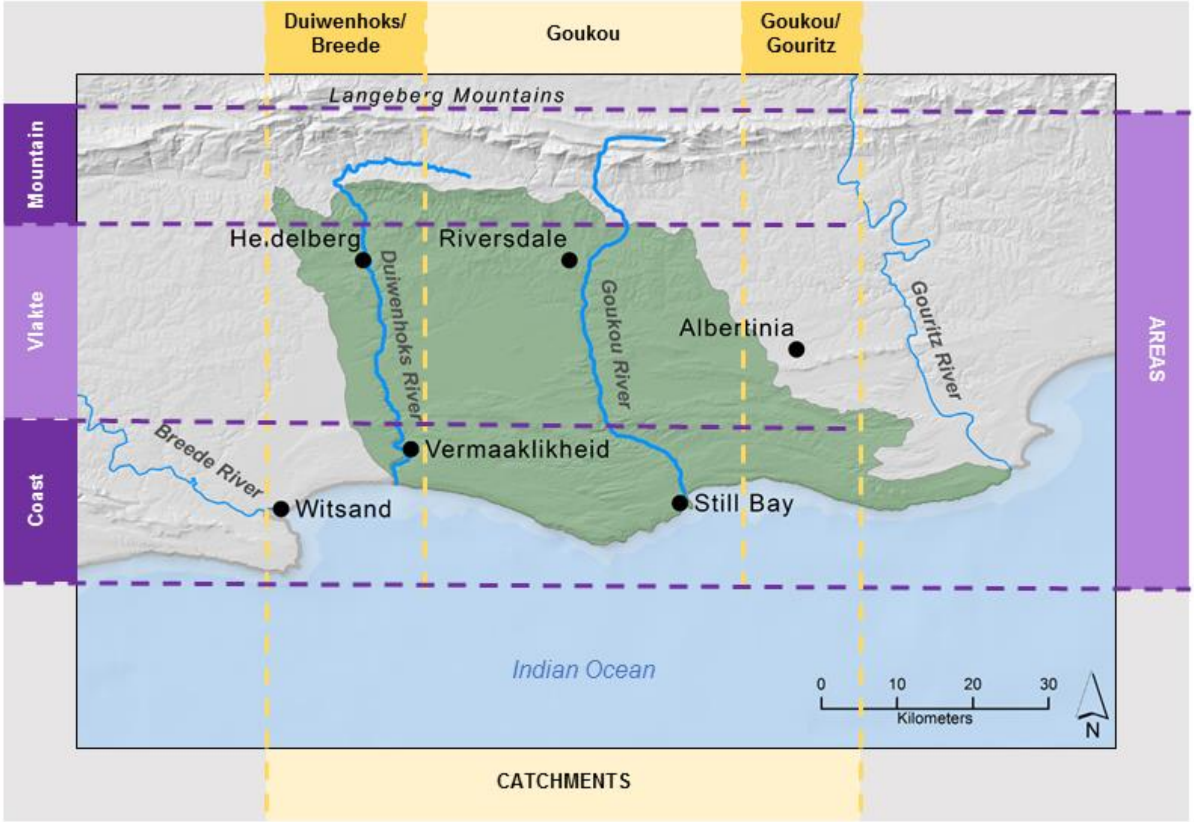

Figure A1.1: Different catchment and area groupings across the research area as a reference for results.

In general, crops, livestock and dairy farming practices dominated the research area. Large-scale crop operations are more easily carried out on the vlakte due to suitable environmental and climatic conditions, while coast and mountain farms tended to be a more diversified mix of crop, livestock and dairy farming due to less favourable conditions (see Figure A1.2).

Figure A1.2: The six grouping describing location characteristics throughout the research area according to catchment (Duiwenhoks/Breede, Goukou and Goukou/Gouritz) and area (mountain, vlakte and coast).

Appendix 2. Farmers Observed Change in Weather Patterns Results

Table A2.1: Farmers' observed change in weather patterns over time grouped according to area (i.e., mountain, vlakte and coast) within catchment (i.e., Duiwenhoks/Breede; Goukou and Goukou/Gouritz).

		RAINFALL	TEMPERATURE	WIND
DUIWENHOKS/ BREEDE	**Mountain**	• Rainfall has become less predictable and increasingly unstable • Increase of single intense rainfall events • Shift of seasonal winter rainfall into summer months • Longer dry periods between rainfall	• Winter season is now cold for shorter period of time	• No noticeable change observed
	Vlakte	• Increase of intense rainfall events • Longer periods of dry spells between rainfall events • Change from predictable drizzle periods over winter (50 + years ago) to more variable/extreme events, but average annual rainfall amount stays consistent overall • Consistently low rainfall years in 1990s and above average rain after 2010 • Seasonal winter rainfall decreased and summer rainfall increased	• Winters are not as cold compared to 20 + years ago • Summers feel hotter (but high uncertainty)	• Less north-westerlies (in winter) and shift to south-westerlies or southerlies
	Coast	• More rainfall in one event	• Hotter daily temperatures over last five years	• No noticeable change observed
GOUKOU	**Mountain**	• Over last 10 years rainfall shifted a month later but no clear pattern • Increase of single intense rainfall events, but average annual rainfall amount stays consistent overall • Spring and summer months have more extreme rainfall events – winter rainfall become less reliable over time	• Summers are generally hotter	• South-easter blows rain to mountains

	Vlakte	• Last 10 years rainfall patterns shifted to later than usual • Fewer wetter winters – traditional winter rainfall shift into summer months • Increase of single intense rainfall events, no longer spread out over drizzle events (compared to 50 + years ago) • Wet and dry years are harder to predict – increased variability • Longer periods of dry spells between rainfall events • Onset of rainfall season shift by a month – from e.g. March to April	• Last five years had more extreme hot and cold days	• Since 2010, less north-west winds and more southerly to easterly winds (from the sea)
	Coast	• More intense rainfall over shorter period of time and more varied – no longer softer rainfall over longer periods of time • 20 + years ago had set seasons (typical spring and autumn rainfall) now highly variable	• Winters are not as cold • More extreme cold and hot events	• 30 + years ago used to get more regular 'berg' wind (hot dry northerly wind blowing from the interior to coastal district) now shifted to more coastal winds
GOUKOU/ GOURITZ	**Mountain**	• No noticeable change observed	• No noticeable change observed	• No noticeable change observed
	Vlakte	• More varied and unusual rainfall patterns over last 15 years • Increase of intense rainfall events • Opposite trend to western extent of Western Cape – receive good rainfall when drought in (e.g.) the Swartland	• No noticeable change observed	• Less north-west winds recently
	Coast	Not surveyed	Not surveyed	Not surveyed

Appendix 3. Rainfall Results

Table A3.1: Spearman’s rank correlation for farmers’ rainfall records (all correlation is significant at the 0.01 level (2-tailed)).

	Farm 1	**Farm 2**	**Farm 3**	**Farm 4**	**Farm 6**	**Farm 7**	**Farm 8**	**Farm 9**	**Farm 10**	**Farm 11**	**Farm 12**	**Farm 13**
Farm 1	1											
Farm 2	.817	1										
Farm 3		.880	1									
Farm 4	.802	.758	.823	1								
Farm 6		.867	.831	.784	1							
Farm 7	.738	.657	.721	.623	.772	1						
Farm 8	.686	.659		.578		.899	1					
Farm 9		.608	.619	.592	.630	.753		1				
Farm 10		.702	.711	.665	.761	.855	.910	.780	1			
Farm 11	.705	.686	.680	.642	.734	.802	.813	.734	.872	1		
Farm 12		.758	.773	.729	.798	.698		.641	.787	.758	1	
Farm 13	.668	.736	.811	.771	.828	.760	.732	.691	.835	.777	.855	1

Table A3.2: Spearman’s rank correlation for rainfall recorded at official weather stations of the South African Weather Service (SAWS) and Agriculture Research Council (ARC) (all correlation is significant at the 0.01 level (2-tailed)).

	Albertinia	**Blackdown**	**Breede**	**Goukou Dam**	**Heidelberg**	**Mon Desir**	**Riversdale ARC**	**Riversdale**	**Still Bay**	**Witsand**
Albertinia SAWS	1									
Blackdown SAWS	.708	1								
Breede SAWS	.673	.717	1							
Goukou Dam	.611	.797	.647	1						
Heidelberg SAWS	.728	.842	.688	.755	1					
Mon Desir SAWS	.701	.844		.683	.847	1				
Riversdale ARC	.718	.772	.705	.709	.801	.803	1			
Riversdale SAWS	.730	.840		.811	.850	.796	.896	1		
Still Bay SAWS	.704	.664	.725	.676	.731	.578	.720	.712	1	
Witsand SAWS	.600	.586		.486	.619	.608	.615	.633	.680	1

Table A3.3: Spearman’s rank correlation for rainfall recorded between farms and official weather stations (all correlation is significant at the 0.01 level (2-tailed)).

	Farm 1	**Farm 2**	**Farm 3**	**Farm 4**	**Farm 6**	**Farm 7**	**Farm 8**	**Farm 9**	**Farm 10**	**Farm 11**	**Farm 12**	**Farm 13**
Albertinia SAWS	.755	.736	.730	.683	.772	.669	.706	.574	.688	.733	.710	.759
Blackdown SAWS	.740	.729	.759	.648	.770	.845	.776	.859	.816	.738	.703	.694
Breede SAWS		.793	.804	.729	.655	.623		.528	.679	.646	.729	.812
Goukou Dam SAWS		.629	.640	.595	.715	.909	.894	.808	.839	.792	.699	.716
Heidelberg SAWS	.760	.751	.81	.705	.805	.816	.774	.553	.771	.731	.744	.702
Mon Desir SAWS	.779	.758	.741	.640		.749	.777		.737	.740	.636	.687
Riversdale SAWS	.759	.763	.803	.709	.980	.775	.830	.635	.778	.779	.791	.779
Riversdale ARC		.780	.777	.733	.851	.844	.902		.864	.839	.745	.855
Still Bay SAWS		.755	.790	.765	.782	.693	.541	.664	.690	.684	.794	.774
Witsand SAWS	.903	.709	.767	.640	.65	.521	.485		.546	.527	.629	.638

Table A3.4: Monthly rainfall according to three ‘extreme’ categories ((less than 10mm; 75th percentile; 95th percentile) divided up into catchment locations. Significance was tested between each time period for each category and group. Where significant, the t-test statistic was greater than 1.96 (corresponding p-value of less than 0.05) and hence was significant at the 95 percent significance level.

	< 10mm		
	Duiwenhoks/Breede	**Goukou**	**Goukou/Gouritz**
Period 1 (before-1981)	18 %^	6 %^	18 %*
Period 2 (1982-1995)	20 %	9 %	11 %^^
Period 3 (1996-2007)	19 %	7 %^	14 %^
Period 4 (2008-present)	23 %*	10 %*	16 %*
	75th percentile		
	Duiwenhoks/Breede	**Goukou**	**Goukou/Gouritz**
Period 1 (before-1981)	26 %	24 %	24 %
Period 2 (1982-1995)	24 %	24 %	27 %
Period 3 (1996-2007)	23 %	26 %	24 %
Period 4 (2008-present)	24 %	25 %	26 %
	95th percentile		
	Duiwenhoks/Breede	**Goukou**	**Goukou/Gouritz**
Period 1 (before-1981)	4 %	4 %	3 %^^
Period 2 (1982-1995)	6 %	5 %	6 %*
Period 3 (1996-2007)	5 %	6 %	5 %
Period 4 (2008-present)	5 %	5 %	6 %*

* indicates significance p<0.05; ^ indicates corresponding value for *

Table A3.5: Monthly rainfall according to three ‘extreme’ categories (less than 10mm; 75th percentile; 95th percentile) divided up into areas. Where significant, the t-test statistic was greater than 1.96 (corresponding p-value of less than 0.05) and hence was significant at the 95 percent significance level.

	< 10mm		
	Coast	**Vlakte**	**Mountain**
Period 1 (before-1981)	22 %	19 %*	10 %*
Period 2 (1982-1995)	21 %	15 %^	7 %^
Period 3 (1996-2007)	19 %	15 %^	6 %^
Period 4 (2008-present)	18 %	20 %*	7 %
	75th percentile		
	Coast	**Vlakte**	**Mountain**
Period 1 (before-1981)	24 %	25 %	25 %
Period 2 (1982-1995)	25 %	24 %	25 %
Period 3 (1996-2007)	25 %	24 %	24 %
Period 4 (2008-present)	26 %	26 %	24 %
	95th percentile		
	Coast	**Vlakte**	**Mountain**
Period 1 (before-1981)	4 %	4 %	4 %
Period 2 (1982-1995)	5 %	6 %	6 %
Period 3 (1996-2007)	5 %	5 %	6 %
Period 4 (2008-present)	5 %	5 %	5 %

* indicates significance $p<0.05$; ^ indicates corresponding value for *

Shapiro-Wilkinson tests for difference from normality indicate that P3 and P4 are normally distributed, whereas P2 is not. Therefore, Wilcoxon tests are used to test for significant differences between P2 vs. P3 and P2 vs. P4, and a Welch two-sample t-test is used to test for differences between P3 vs. P4. All these periods are different from one another.

```
                                    ###Shapiro tests for normality - parametric

P2
Shapiro-Wilk normality test

data:  F3_t$P2
W = 0.83482, p-value = 0.006346

P3
Shapiro-Wilk normality test

data:  F3_t$P3
W = 0.95719, p-value = 0.5484

P4
Shapiro-Wilk normality test

data:  F3_t$P4
W = 0.94289, p-value = 0.3541

                              ###Tests for significant difference between periods

P2/P3
Wilcoxon rank sum test

data:  F3_t$P2 and F3_t$P3
W = 27, p-value = 6.29e-06
alternative hypothesis: true location shift is not equal to 0

P2/P4
Wilcoxon rank sum test

data:  F3_t$P2 and F3_t$P4
W = 282, p-value = 3.857e-08
alternative hypothesis: true location shift is not equal to 0

P3/P4
Welch Two Sample t-test

data:  F3_t$P3 and F3_t$P4
t = 12.748, df = 26.153, p-value = 9.931e-13
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 51.16319 70.82740
sample estimates:
mean of x mean of y
 29.49000 -31.50529
```

Box A3.1: Tests relating to Figure 3 (Rainfall variability between Old and New planting seasons).

Appendix 4. Temperature Results

Table A4.1: Regime shifts according to seasons (tri-month average temperature) for Mossel Bay.

Season	Number of regime shifts	Periods of regimes	Mean average temperature	Direction of change per regime period
Winter	3	1920 – 1935 1936 – 2014 2015	14.8 15.3 14.1	Down Up Down
Spring	5	1920 – 1938 1939 – 1948 1949 – 1996 1997 – 2007 2008 – 2014	16.8 17.3 16.6 17.6 16.7	Down Up Down Up Down
Summer	5	1921 – 1939 1940 – 1950 1951 – 1998 1999 – 2008 2009 – 2015	20.6 21.1 20.4 21.5 20.8	Down Up Down Up Down
Autumn	5	1920 – 1931 1932 – 1952 1953 – 1997 1998 – 2014 2015	18.2 18.7 18.2 18.8 17.9	Down Up Down Up Down

Table A4.2: Regime shifts according to seasons (tri-month average temperature) for Riversdale.

Season	Number of regime shifts	Periods of regimes	Mean average temperature	Direction of change per regime period
Winter	2	1973 – 2010	12.9	Up
		2011 - 2014	11.9	Down
Spring	4	1973 - 1996	16.8	Down
		1997 – 2004	17.7	Up
		2005 – 2013	16.2	Down
		2014	17.1	Up
Summer	---	1973 – 2014	21.9	N/A
Autumn	---	1973 – 2014	18.3	N/A

Appendix 5. Wind Results

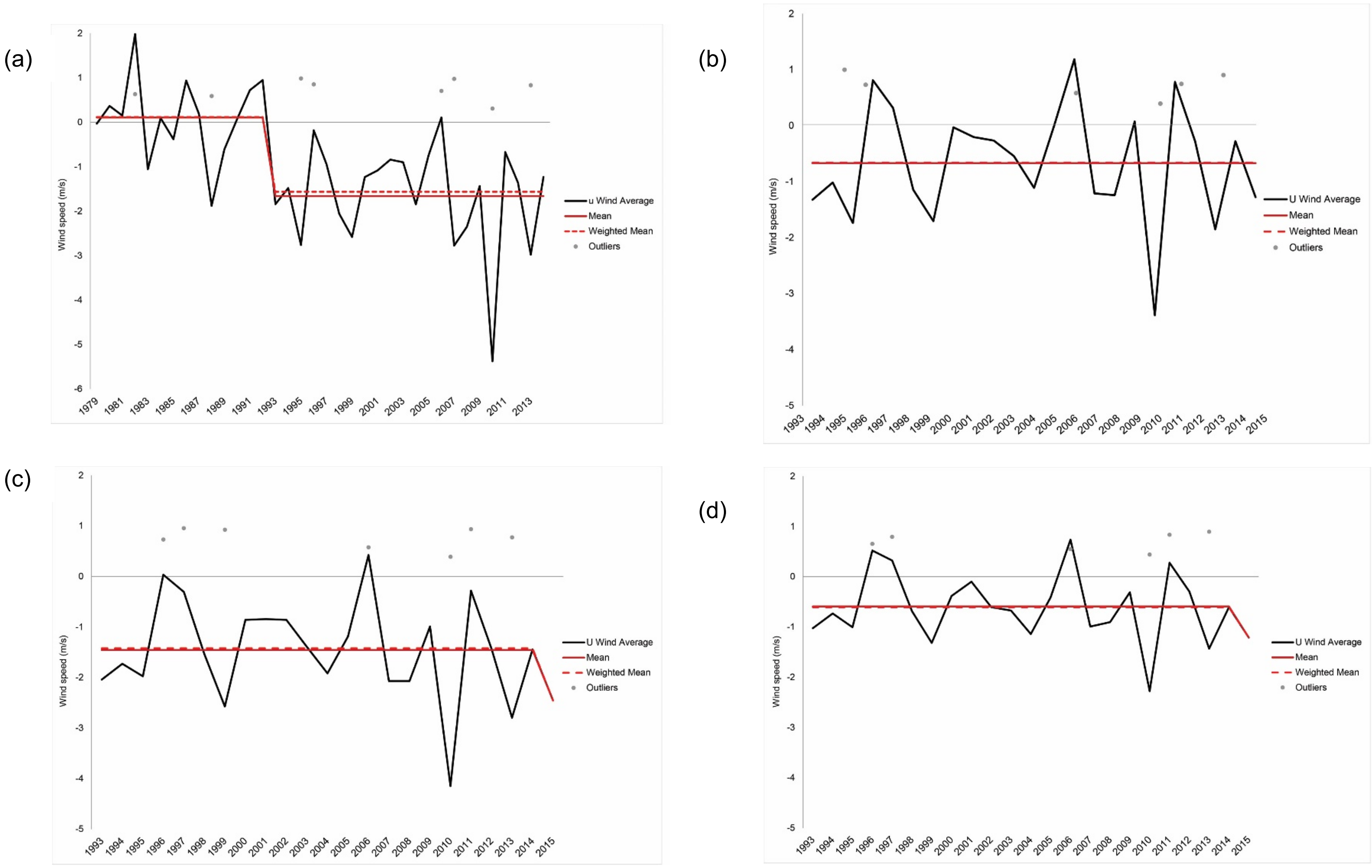

Figure A5.1: Summer mean values for U component of wind speed for (a) NCEP-DOE, (b) scatterometer aggregate, (c) Witsand and (d) Mossel Bay.

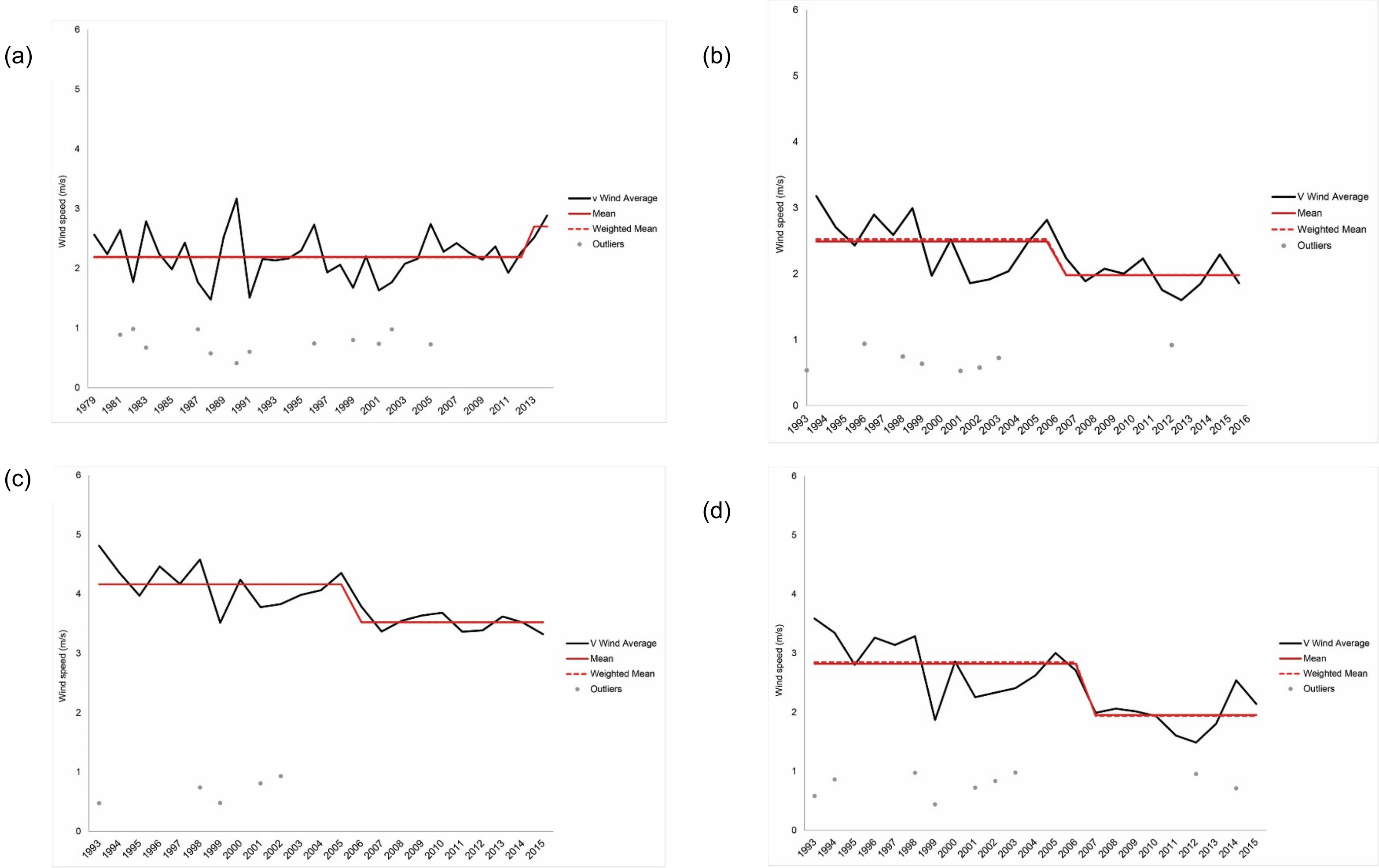

Figure A5.2: Summer mean values for V component of wind speed for (a) NCEP-DOE, (b) scatterometer aggregate, (c) Witsand and (d) Mossel Bay.

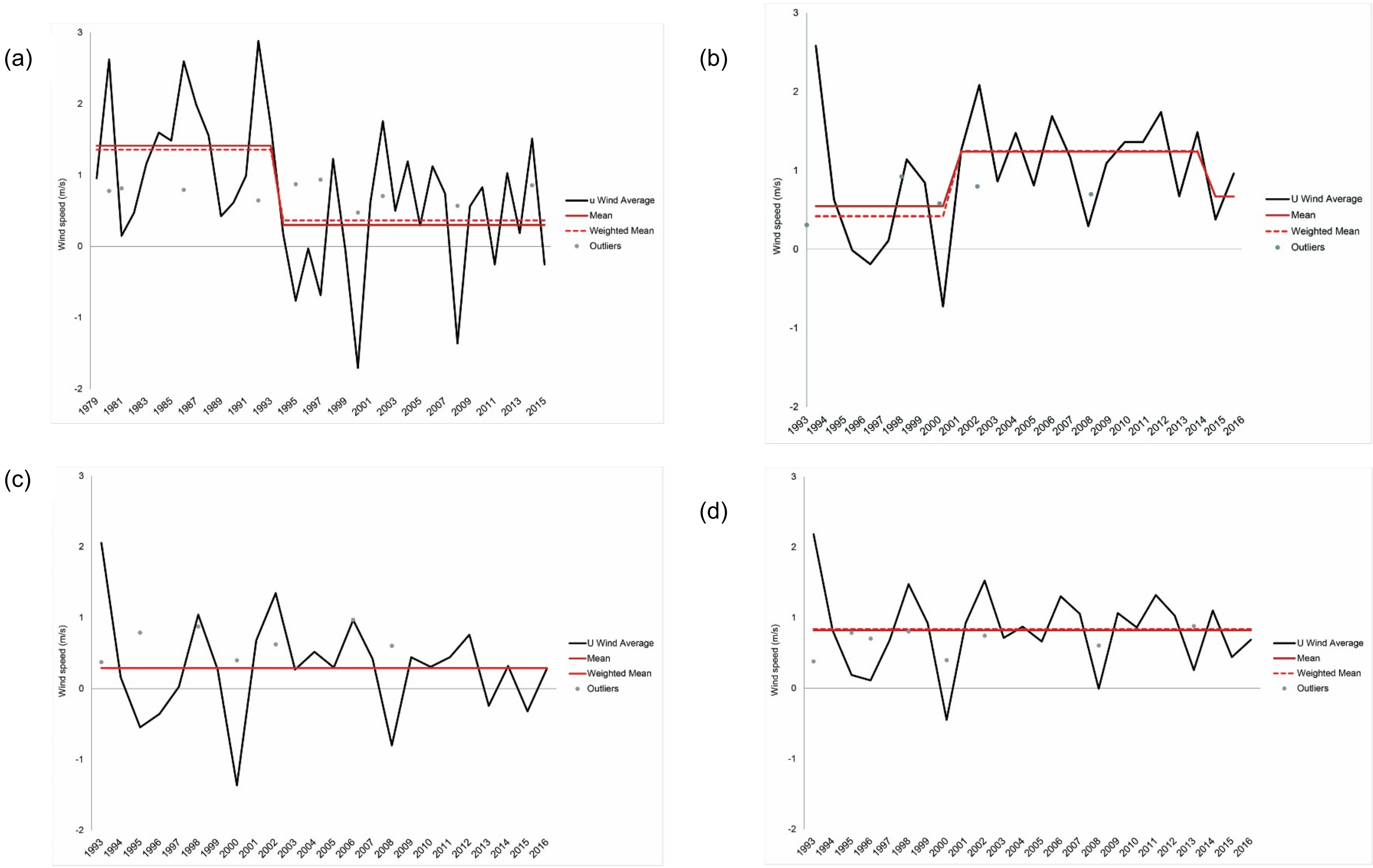

Figure A5.3: Autumn mean values for U component of wind speed for (a) NCEP-DOE, (b) scatterometer aggregate, (c) Witsand and (d) Mossel Bay.

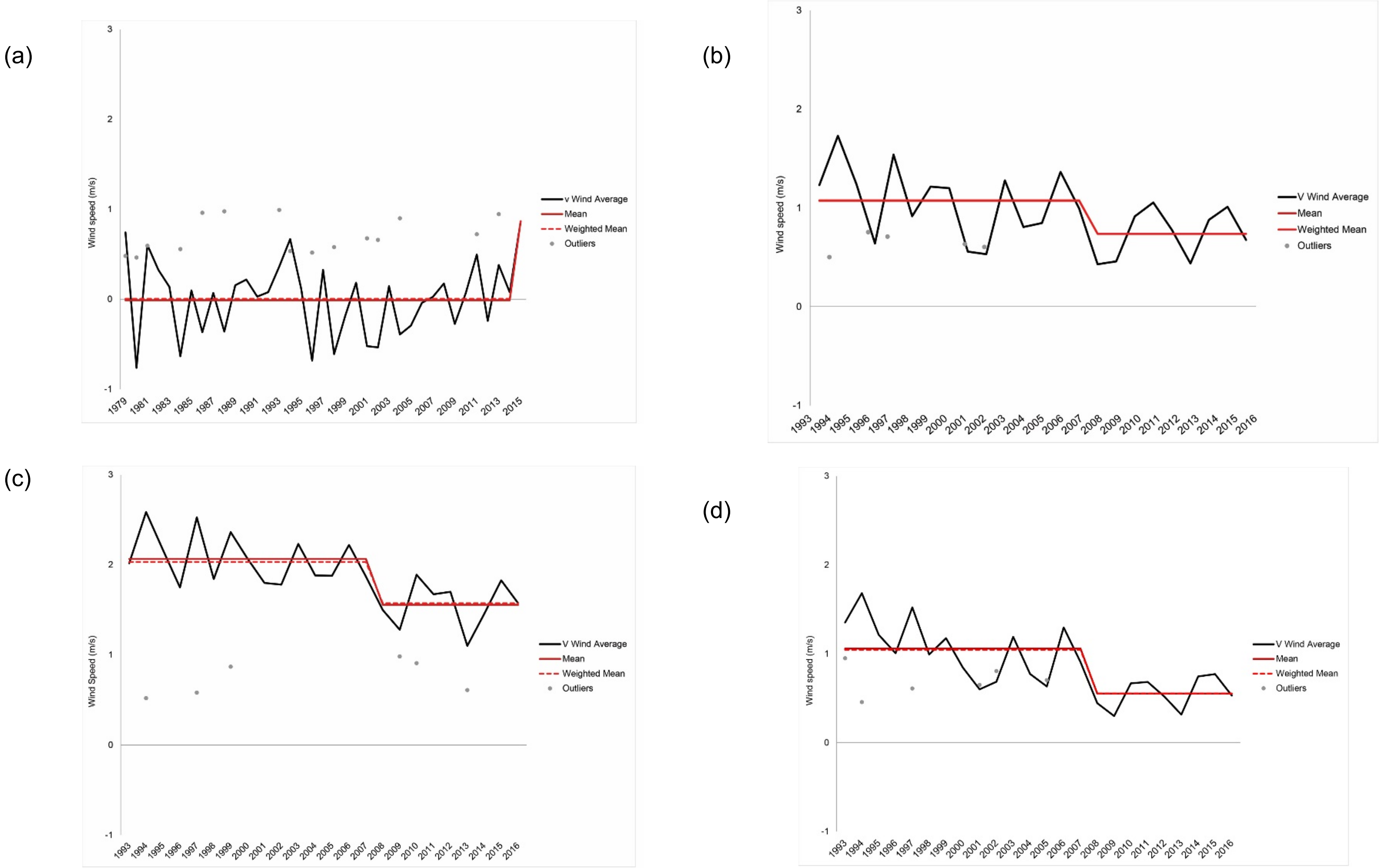

Figure A5.4: Autumn mean values for V component of wind speed for (a) NCEP-DOE, (b) scatterometer aggregate, (c) Witsand and (d) Mossel Bay.

Table A5.1: Wind regime patterns for annual and austral seasons between near- and off-shore time series analysing the mean.

	NCEP-DOE	Aggregate	Witsand	Mossel Bay	Comments
Annual U Wind	1992/1993 ↓ 2013/2014 ↓	2013/2014 ↓	2013/2014 ↓	2013/2014 ↓	**Comparable:** The peaks and toughs across all four data sets, where comparable, were consistent (for example, higher peaks in 1996 and 2005; lower toughs in 1999 and 2010).
Annual V Wind	1996/1997 ↓ 2009/2010 ↑	—	2006/2007 ↓	2006/2007 ↓	**Non-comparable:** Aggregated data were qualitatively more similar to Witsand and Mossel Bay points, despite not displaying regime shifts. Inshore dynamics were more pronounced than the aggregate point.
Austral Summer U Wind	1992/1993 ↓ 2006/2007 ↓	2006/2007 ↓	2006/2007 ↓	2006/2007 ↓	**Comparable:** Decreasing westerlies are relative to increasing easterlies, which correspond to increasing upwelling in the system and thus more productivity on the Agulhas Bank. This is consistent with findings from Blamey et al. (2012) and Lamont et al. (2017) regarding increased upwelling on the Agulhas Bank over time.
Asutral Summer V Wind	2011/2012 ↑	2008/2009 ↓	2005/2006 ↓ 2014/2015 ↓	2005/2006 ↓ 2013/2014 ↑	**Non-comparable:** Witsand and Mossel Bay points agree qualitatively with aggregated scatterometer points. Near-shore south easterly winds have appeared to have shifted to east rather than south from mid-2000s. However, southerly winds have increased off-shore towards the end of the time series according to NCEP-DOE and Mossel Bay results.
Austral Winter U Wind	2011/2012 ↑	2014/2015 ↓	2014/2015 ↓	2014/2015 ↓	**Non-comparable:** However, all four time series indicate a strong peak between 2012 and 2013, thus possibly influencing the NCEP-DOE results as the off-shore time series only runs until 2014. It is noted that all of the time series have similar peaks and toughs.
Austral Winter V Wind	1995/1996 ↓ 2009/2010 ↑	—	—	—	**Non-comparable:** Near-shore wind results suggest that there was no significant change during winter, which is contradicted by off-shore winds that show an increase in northerly winds from the mid-1990s to late 2000s.

Table A5.2: Wind regime patterns for specific seasons between near- and off-shore time series analysing the mean.

	NCEP-DOE	**Aggregate**	**Witsand**	**Mossel Bay**	**Comments**
Winter U Wind	1987/1988 ↑ 2012/2013 ↑	2014/2015 ↓	2014/2015 ↓	2014/2015 ↓	**Non-comparable:** It should be noted that the second regime shift for the NCEP-DOE time series is at the end of the time series and may have insufficient data. Both near- and off-shore time series have similar very low troughs in 2011 and all of the time series show a peak in 2012/2013 (which subsequently decreases in the more complete scatterometer series that run until 2016).
Winter V Wind	1998/1999 ↓ 2009/2010 ↑	2010/2011 ↑	2014/2015 ↑	2014/2015 ↑	**Non-comparable:** Aggregate scatterometer results show a regime shift in 2010/2011 towards increasing southerly winds. Witsand and Mossel Bay are internally consistent, but only indicate a regime shift in 2014/2015 towards increasing southerly winds. Scatterometer and NCEP-DOE time series are consistent in that they show increasing southerly winds but at different times during the 2000s.
Spring U Wind	2013/2014 ↓	2013/2014 ↓	2013/2014 ↓	2013/2014 ↓	**Comparable:** In the scatterometer data, the new regime shift has resulted in wind direction changing from west to east in Witsand, although wind speed is weak. Mossel Bay's westerly direction also decreased, but remains westerly and weak in speed.
Spring V Wind	1996/1997 ↓ 2005/2006 ↑	2015/2016 ↑	2007/2008 ↓	2007/2008 ↓	**Non-comparable:** Similarly to Autumn V Wind, NCEP-DOE and scatterometer time series give an opposite trend. Aggregate scatterometer data are qualitatively similar to Witsand and Mossel Bay. It should be noted that the regime shift for Aggregate scatterometer time series is at the end of the time series and may have insufficient data.

Table A5.3: Wind regime patterns for annual and austral seasons between near- and off-shore time series analysing variance.

	NCEP-DOE	Aggregate	Witsand	Mossel Bay	Comments
Annual U Wind	1987/1988 ↑ 2006/2007 ↑	2011/2012 ↑	2012/2013 ↑	2011/2012 ↑	Variability increased over time across all data sets where aggregated, Witsand and Mossel Bay experienced increased variability after 2010, whereas NCEP-DOE results indicated mid-2000s (consistent with Blamey et al., 2012).
Annual V Wind	——	2008/2009 ↓	2001/2002 ↓ 2014/2015 ↓	2000/2001 ↓ 2008/2009 ↓	Variability decreased over time for scatterometer points and did not show any change in the NCEP-DOE time series.
Austral Summer U Wind	1989/1990 ↓	——	——	——	No change in variability occurred for scatterometer points and variability decreased into the 1990s according to NCEP-DOE results.
Asutral Summer V Wind	——	2012/2013 ↓	——	2010/2011 ↓	Variability decreased after 2010 for the aggregate and Mossel Bay points, however did not change for NCEP-DOE and Witsand points.
Austral Winter U Wind	1988/1989 ↑ 2013/2014 ↑	2002/2003 ↓	2002/2003 ↓	2002/2003 ↓ 2014/2015 ↓	Over time, variability increased for the NCEP-DOE points and decreased for all scatterometer points.
Austral Winter V Wind	2010/2011 ↓	2001/2002 ↓	2001/2002 ↓ 2011/2012 ↓	2001/2002 ↓	Variability decreased across both NCEP-DOE and scatterometer points, with shifts taking place in the early 2000s for the scatterometer points and again after 2010 for the NCEP-DOE and Witsand points.

Table A5.4: Wind regime patterns for specific seasons between near- and off-shore time series analysing variance.

	NCEP-DOE	**Aggregate**	**Witsand**	**Mossel Bay**	**Comments**
Summer U Wind	—	—	—	—	No change in the variance was detected for both NCEP-DOE and scatterometer points.
Summer V Wind	2013/2014 ↑	—	—	—	Variability only increased at the end of the NCEP-DOE time series in the late 2000s, whereas the scatterometer points did not change.
Autumn U Wind	2014/2015 ↑	2015/2016 ↓	2014/2015 ↑	2002/2003 ↓ 2015/2016 ↓	NCEP-DOE and Witsand results showed an increase in variability after 2014, whereas the aggregate and Mossel Bay points decreased.
Autumn V Wind	—	—	2015/2016 ↓	2010/2011 ↓	Variability decreased after 2010 for Witsand and Mossel Bay points, however did not change for NCEP-DOE and aggregate points.
Winter U Wind	2013/2014 ↑	—	—	—	Variability only increased at the end of the NCEP-DOE time series and the scatterometer points did not change over time.
Winter V Wind	—	2008/2009 ↓	2001/2002 ↓	2008/2009 ↓	There was on change in variability for the NCEP-DOE point, however the scatterometer points showed a decrease in variability after 2008 for the aggregate and Mossel Bay points, and after 2001 for Witsand.
Spring U Wind	2011/2012 ↑	—	—	—	NCEP-DOE results show an increase in variability after 2011, but scatterometer points do not show any change.
Spring V Wind	—	—	—	—	No changes in variability were detected for all time series.