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Developing an Integrated Ocean Observing System for New Zealand

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New Zealand (NZ) is an island nation with stewardship of an ocean twenty times larger than its land area. While the challenges facing NZ's ocean are similar to other maritime countries, no coherent national plan exists that meets the needs of scientists, stakeholders or kaitiakitanga (guardianship) of NZ's ocean in a changing climate. The NZ marine science community used the OceanObs'19 white paper to establish a framework and implementation plan for a collaborative NZ ocean observing system (NZ-OOS). Co-production of ocean knowledge with Māori will be embedded in this national strategy for growing a sustainable, blue economy for NZ. The strengths of an observing system for a relatively small nation come from direct connections between the science impetus through to users and stakeholders of an NZ-OOS. The community will leverage off existing ocean observations to optimize effort and resources in a system that has historically made limited investment in ocean observing. The goal of the community paper will be achieved by bringing together oceanographers, data scientists and marine stakeholders to develop an NZ-OOS that provides best knowledge and tools to the sectors of society that use or are influenced by the ocean.

Keywords: ocean observation network, ocean modeling, marine community, Mātauranga Māori, changing ocean climate

INTRODUCTION

New Zealand (NZ) is an island nation with stewardship of an ocean area twenty times its landsize, yet it does not currently have an ocean observing system (OOS). NZ's marine space spans the subtropics to the subantarctics with islands to the north, south and east far beyond its two main islands (**Figure 1**). The shelf sea environment includes broad plateaus, narrow steep shelves and wide continental shelves incised with submarine canyons. Warm, saline subtropical water (STW) arrives in NZ from the north via the South Pacific Gyre and East Auckland Current (EAUC). From the south, subantarctic water (SAW) with lower salinity and temperature flow near NZ in the Southland Current adjacent to the South Island and in the northernmost branches of the Antarctic Circumpolar Current (Chiswell et al., 2015). Dynamic processes in the shelf seas include strong tidal flows in Central NZ, large internal tides and significant terrestrial inputs of freshwater, sediment and carbon after storms (Zeldis and Swaney, 2018; Stevens et al., 2019).

In dollar terms, NZ's marine economy is estimated to be worth around $NZ four billion (Ministry for the Environment [MfE], 2016). NZ's exclusive economic zone (EEZ) underpins an emerging blue economy; it is globally recognized to support high biodiversity of seabirds and marine mammals, a productive fisheries sector and a growing aquaculture industry. Stewardship of this large area's resources and values requires robust scientific knowledge and understanding to ensure sustainable management of marine ecosystems, which are influenced by multiple stressors and a changing climate.

Indigenous perspectives are a key aspect of NZ's policy and science landscape and are particularly relevant in developing effective ocean stewardship that is informed by an NZ-OOS. The government's Vision Mātauranga (VM) policy was developed to unlock the potential of Mātauranga Māori, which is broadly defined as Māori or traditional knowledge, comprehension or understanding of the universe (Ministry of Research Science and Technology [MoRST], 2007). Guardianship or kaitiakitanga of Aotearoa's (te reo Māori for NZ) land and sea is an intrinsic concept in Māori science. Joint efforts between Mātauranga Māori and western science practices are becoming more common providing a holistic, inclusive, system-wide knowledge of the natural world.

The Why and Why Now

New Zealand faces similar challenges – managing multiple stressors, climate change, sea-level rise, ocean acidification, and impacts from changing terrestrial fluxes – as other maritime countries. A sense of urgency exists to understand, predict and mitigate, at a national scale, the ocean and ecosystem responses to these global problems (Stevens and O'Callaghan, 2015). **Figure 2** outlines high-level themes of interest for users and beneficiaries of an NZ-OOS and its integrated data products. Underlying these themes are six key issues identified by the NZ community as kaitiakitanga priorities.

1. Land-sea connectivity and associated stressors (e.g., sedimentation, contaminants).
2. Coastal and bluewater carbon budgets.
3. Sustainable extraction of marine resources (e.g., seabed mining, tidal energy).
4. Sustainable seafood sector including both wild caught fisheries and aquaculture.
5. Multi-scale drivers and response of the ocean state.
6. Maritime safety and transport optimization.

The concept of an OOS is not new to NZ; factors relating to national priorities and NZ's policy and science systems, combined with limited resources have inhibited the development of an NZ-OOS. Resources commensurate with a population of ∼5 million people and a dominant agricultural sector for many years underpinned a landward focus (Hendy and Callaghan, 2013). Long term coastal warming (Shears and Bowen, 2017) and recent variability in fish stocks and impacts on aquaculture along with extremes in ocean temperature have prompted an urgent rethink of how marine sectors will respond to changing environmental drivers (Salinger et al., 2019).

The NZ Science System

The NZ science system is small, which can be both advantageous and limiting in terms of developing and implementing an OOS. The OECD Research & Development (R&D) survey identified R&D as a percentage of GDP as 1.263 and researchers per thousand employment (FTE) as 7.94 (OECD, 2018). The R&D expenditure proportion is around half the OECD average. Several significant changes have taken place in the NZ science system sector over the last three decades. In 1991 Crown Research Institutes (CRIs) were formed, essentially restructuring the Government science sector from a single research provider (the Department of Scientific and Industrial Research, DSIR) into several institutes that were built around a hybrid business and public-good model.

Marine scientist capacity is modest across NZ. Major employers in the sector are the National Institute of Water and Atmospheric Research (NIWA, a CRI), four (out of seven) universities, Meteorological Service of New Zealand (MetService), MetOcean Solutions and the Cawthron Institute (independent research organization). Research foci of the national institutes has evolved over the past 25 years from public-good science to stakeholder "co-production." Current hallmarks of the funding landscape include (1) separation between climate science and ecosystem research, (2) under-valuing of sustained monitoring of the ocean and (3) inability to support long term (greater than 5 years) projects. Funding for the development and implementation of an NZ-OOS will require a combination of long-term government investment, organizational co-investment and private sector contributions.

NZ-OOS Planning Workshop

A successful workshop with multi-institutional support was held in August 2018. Participant organizations were NIWA, Cawthron, MetService, Centre for Space Science Technology (CSST), Ministry for Primary Industries (MPI), Ministry for the Environment (MfE), Department of Conservation (DOC), NZ Navy, Defence Technology Agency (DTA), Auckland and Otago Universities, and the Coastal Special Interest Group (C-SIG) that represents the national network of regional councils with jurisdiction out to 12 nautical miles. NIWA's Pou Hononga for Māori and the Marine Environment provided a Mātauranga Māori contribution. Outcomes from workshop discussions form the basis of this white paper.

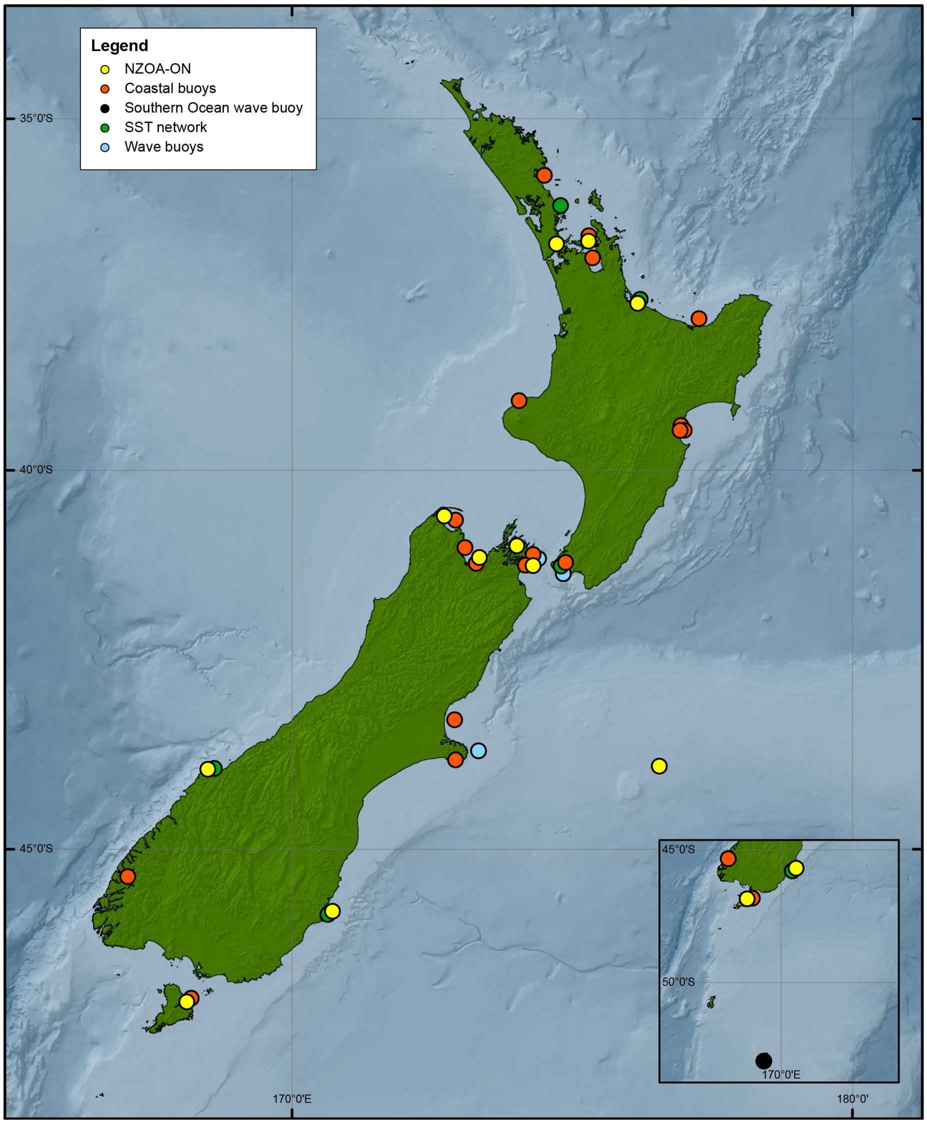

FIGURE 1 | Map of New Zealand (NZ) with observational assets are overlaid on the bathymetry. Assets shown are wave buoys (blue dots), coastal buoys (orange dots), NZOA-ON (yellow dots), SST network (green dots) and the Southern Ocean wave buoy (black dot).

OCEAN OBSERVATIONS

Present State of NZ Observations

The two longest sea surface temperature (SST) monitoring sites are from opposite ends of Aotearoa, with the Portobello station (University of Otago) started in 1953, followed by Leigh (University of Auckland) in 1967. Growth and reduction of a coastal SST monitoring network has occurred over intervening years (Greig et al., 1988) and as of writing there are five coastal SST stations (**Figure 1**). Other long term observations are the sea level network around NZ[1], which has also had to rationalizatise the number of sites in recent years. Two biophysical moorings were located at 41°S, 178°30′E and 46°40′S, 178°30′E in STW and SAW for 10 years from 2002 to 2012 to resolve oceanic carbon budgets (Nodder et al., 2016).

University of Otago and NIWA established the NZ Ocean Acidification observing network (NZOA-ON) with 14 sites around NZ, linked to the Global Ocean Acidification Observing Network (GOA-ON). The NZOA–ON expands on the successful *Munida* transect off the coast of the South Island established in 1998 that is the southern hemisphere's longest-running record of pH (Bates et al., 2014) and surface variability across STW and SAW (Currie et al., 2011).

There are few wave and coastal moorings considering the length (15,000 km) and variability of NZ's coastline. The Firth of Thames mooring is the longest at 20 +years (1998 to now, Zeldis and Swaney, 2018). Sampling durations are typically shorter (<10 years), generally deployed by regional councils

[1] https://www.niwa.co.nz/our-services/online-services/sea-levels

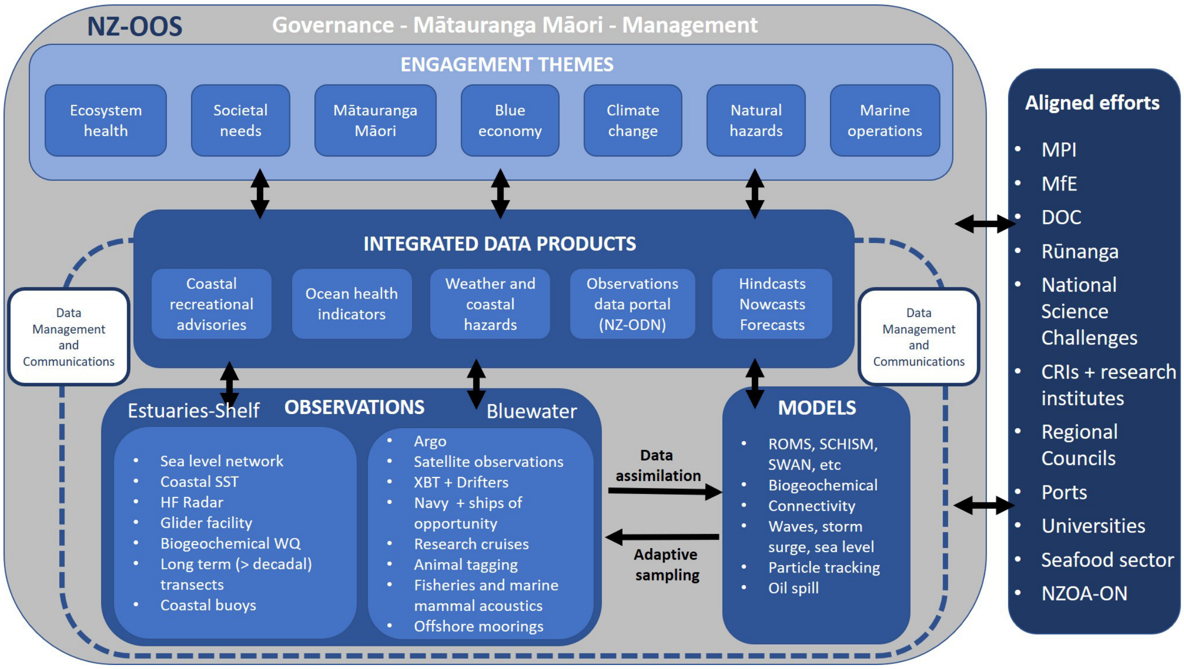

FIGURE 2 | Framework for the NZ-OOS building on existing efforts in NZ. The proposed structure illustrated has been adapted from that used for the Southeast Coastal Ocean Observing Regional Association.

in conjunction with Cawthron or NIWA and tend to have a focus on surface coastal water quality issues and sedimentation (**Figure 1**). Passive acoustics moorings to characterize marine mammal migratory pathways have also been deployed for 12 months in Central NZ. Recently, ocean gliders have been used to observe NZ shelf seas processes with 20 missions since 2015 (O'Callaghan, pers comm).

Bluewater observations have historically been dominated by mooring deployments of less than 2 year duration and voyage-based hydrographic surveys to characterize boundary currents around NZ. For example, Tasman Sea boundary experiments (Stanton and Moore, 1992), and variability studies of the East Auckland Current (EAUC) (e.g. Stanton et al., 1997; Fernandez et al., 2018, and many others), Norfolk Ridge (Sutton and Bowen, 2014) and, Southland Current (Sutton, 2003).

New Zealand has been an important part of the Global Argo program since the early 2000s with NIWA's vessel R/V Kaha Ora deploying 1287 floats in the Pacific, Indian and Southern Oceans. NIWA's RV Tangaroa has deployed a further 147 floats. The most southerly wave buoy in the world has been maintained by the MetService since 2016 at 52.7°S. EXpendable Bathy Thermographs (XBTs) have been deployed along two tracks ending in NZ roughly four times per year (Sutton et al., 2005). XBTs are also routinely deployed by the NZ Navy.

Plans for a Future Observational Network

Building on the framework of existing observations, a series of workshops will be held with scientists and key stakeholders in regulatory agencies, CRIs and universities. These workshops will define the mix of what infrastructure is most likely to address the key research themes in an ambitious and affordable way for the next 1, 5 and 10 years. With international experience to draw on, we are well placed to implement an NZ-OOS in a cost-effective manner to achieve meaningful and sustained observational coverage with potential to grow strategically in the future.

We propose a number of sentinel sites (analogous to the National Reference stations in the Australian IMOS context) that are physically occupied at adequate frequency for biogeochemical and physical water sampling of essential ocean variables (EOVs). Sentinel sites will be instrumented appropriately to develop environmental baselines in a changing climate. In addition, we will identify a backbone network of high frequency (HF) radar and glider deployments to provide boundary current data, and context for model data assimilation.

A creative approach will be required to get meaningful coverage across NZ's large EEZ. It is recognized that the NZ seafood sector provides an opportunistic pathway for data collection and effort is already being made with this sector. The NZ Navy has plans to facilitate oceanographic data collection. By using vessels of opportunity, we can optimize data coverage while minimizing costs to NZ-OOS.

OCEAN MODELING

Present Status

Physical and biogeochemical ocean modeling is undertaken by a number of organizations with each team having their preferred model (ROMS, Schism/SELFE, SWASH, SWAN, WW3, Gerris, and Basilisk), domain (coastal to global scale), grid (structured, unstructured, curvilinear or adaptive), timeframe (days, weeks to years) and parameters (physics, biogeochemistry, sediment transport, waves). Typically these models have been developed either for specific process studies (e.g., Hadfield et al., 2007), or in response to stakeholder requirements and resource consent applications. Operational forecasts of waves, storm surge and barotropic circulation exist at the national scale.

An OOS is acknowledged as incomplete without a nationally coordinated ocean modeling program. The benefits are 2-fold: observational design is optimized from model simulations while modeling efforts are constrained by relevant observations. The Australian Integrated Marine Observing system (IMOS) program did not initially include funding for ocean modeling. Australian Coastal and Oceans Modeling and Observations (ACOMO) was born 5 years after IMOS and provides a valuable national perspective on modeling and observational networks. It is considered prudent to incorporate an integrated modeling system in NZ-OOS from the outset.

Plans for Ocean Modeling and Data Assimilation

Close connections between the NZ science community and stakeholders means that knowledge relevant to industry is paramount. A national modeling framework that assimilates new and historic observations is essential for an integrated NZ-OOS. In this way the observations and modeling initiatives are intimately coupled. A high resolution coastal ocean reanalysis (ocean state estimate) is being developed by MetOcean Solutions[2]. This modeling system will include a 25-year data assimilating physical model and will provide open access daily coastal ocean forecasts in the next 1 to 3 years. Model hindcasts of physics and biogeochemistry are being developed by NIWA at the EEZ scale. Observation impact experiments (Kerry et al., 2018) and observing system simulation experiments (Kourafalou et al., 2015) provide both context for ongoing model development and the evolution of the observing system.

DATA, TOOLS, AND DELIVERY

Open Data and Legacy Data Issues

Open access to data underpins OOS frameworks globally and success of the proposed NZ-OOS will be intertwined with availability of data, data uptake and publications. The necessary shift in perspective is underway in NZ but is happening against a backdrop of a better understanding of what open data means and resourcing open data. The proprietary nature of data from commercial projects is questionable, particularly if they were collected with resources and capacity co-supported by government funding.

Open data is universally recognized as a "good thing" (Schmidt et al., 2016), however, there remain issues relating to quality assurance and usage restrictions. Stronger mandates from the funding agencies will strengthen the requirements for data sharing. New Zealand Government Open Access and Licensing [NZGOAL], 2019 provides a framework for open data to apply to all sector data.

In 2017 the New Zealand Ocean Data Network (NZODN)[3] was launched, modeled on the Australian Open Data Network (AODN). It is now a collaboration between NIWA and Land Information New Zealand (LINZ). The AODN Portal provides access to all available Australian marine and climate science data and provides the primary access to IMOS data. A key point of difference is that IMOS is national collaborative research infrastructure, supported by Australian Government – no equivalent exists yet in the New Zealand system, although this is our aspiration. The NZODN and AODN are regional reflections of a growing international trend for open data resources.

Data Science Products and Tools

The evolution of useful data products becomes iterative as users tend to be resourceful and can use data in ways not obvious in the initial planning. This *ad hoc* co-production can be enhanced through better and wider end-user input to the design phase. The impact of the NZ-OOS will be enhanced if it provides easy pathways for uptake, manipulations and re-dissemination from the outset. Stakeholders are likely users of tools and while uptake may be slow they will provide robust interrogation of the results whereas the public are likely to be fast and idiosyncratic in their usage. Both pathways provide connections between science product and government policy.

Mātauranga Māori

It is possible that NZ can be among the world leaders in the integration of traditional knowledge with western science into an NZ-OOS. Mātauranga-a-iwi is being advanced through Treaty settlements legislation and other negotiated agreements, which is creating co-management arrangements and increased participation by Māori in all areas of ocean research, policy and management. Māori are seeking Mātauranga and science advice to address aspirations in halting ocean degradation through adaptive management strategies, inclusive of both traditional and contemporary forms of kaitiakitanga. There is potential for non-sacred traditional knowledge to be shared through knowledge platforms such as Māori environmental forums and Rûnanga (a recognized iwi or tribal authority) therefore enhancing uptake and integration.

TOWARD AN INTEGRATED NZ-OOS

The NZ-OOS is a bottom-up community-driven initiative and its success depends on a joint, inclusive approach. Overcoming longstanding limitations established by the hybrid science model over nearly 30 years will require ongoing and meaningful cross-institutional engagement. With collaborative governance, broad participation, and sustainable central government funding, NZ is fully capable of implementing a world-leading OOS that

[2]https://www.moanaproject.org/

[3]https://nzodn.nz/

provides effective kaitiakitanga of its vast EEZ in a changing climate. This white paper is the first step in the implementation process. **Figure 2** provides the framework for the proposed NZ-OOS from governance through to details of data collection platforms. Ecosystem-based management tools that are being developed in National Science Challenges (aligned efforts) will allow integration of monitoring components at the 10-year time scale.

Without doubt the biggest hurdle to overcome is sufficient and sustained resourcing of the proposed NZ-OOS. Often the limiting factor in the development of a highly sophisticated ocean observing system such as the one detailed here is the available funding mechanisms. Observational data streams obtained via existing research programs from central government funding will be the backbone of NZ-OOS in the short- to medium term. Resources to support working group progress will come from individual organizations. Long-term funding was identified by the community as much more difficult to secure. Ultimately, this will require a business case to be submitted to the NZ government to fund future ocean infrastructure.

By the end of the first year, we aim to develop a draft strategic plan built on a well-designed framework and collaborative governance structure. With a sound plan in place, a business case for funding an NZ-OOS will be developed. Many of the elements, both observational and modeling, already exist in NZ. It is encouraging that the NZ-OOS framework has begun to provide, since the August 2018 workshop, a mechanism for new connections of aligned efforts from organizations (**Figure 2**).

To achieve the year 1 objective, we will establish:

1. A pan-NZ steering committee and governance board.
2. Four working groups focused on estuaries to shelf, bluewater, data systems, and communications. The scope of each group will be expansive to overcome organization and science discipline silos.
3. A catalog of observational assets and existing marine data for NZ (**Figure 1**).
4. A strategy for implementing Mātauranga Māori in an NZ-OOS.

After 5 years, the NZ-OOS could include:

1. A widely subscribed data system built around the NZ-Ocean Data Network (NZ-ODN) providing data to a wide range of users.
2. A network of coastal monitoring assets in key regions across a range of organizations that follow standardized data exchange protocols.
3. Access to model hindcast and reanalysis products for simulating and visualizing NZ's EEZ.
4. The ability for rapid response for forecasting coastal hazards, oil spill trajectories, and biosecurity risk.
5. Implementation of a network of sentinel sites for observing EOVs along latitudinal and anthropogenic gradients.
6. Develop and implement sentinel fish and marine megafauna data collection programs that indicate ecosystem change.

After ten years, the NZ-OOS could include:

1. A widely accessible OOS visualization system that enables society to engage with ocean data in new and exciting ways.
2. Data assimilating operational models providing near-real time forecasting of our entire EEZ.
3. Commitment from the seafood industry, with the entire fishing fleet and aquaculture farms established as observing platforms.
4. Integration of ecological layers and the inclusion of, biogeochemical and molecular ocean data through aligned sampling programs.
5. Successful integration of Mātauranga Māori into a national OOS framework.

To summarize, with the integration of Mātauranga Māori, NZ's science, technologies and closely connected community provides a timely opportunity to develop an exemplary NZ-OOS that will provide a world-leading example of ocean stewardship, and enable ocean knowledge, data and tools to be openly accessed for the benefit of NZ's economy, social well-being and ocean health.

AUTHOR CONTRIBUTIONS

JO led the writing and NZ-OOS workshop. CS, MR, and CC contributed to respective sections of the manuscript. All other authors either participated in the August workshop or provided feedback on various versions of the manuscript.

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