Comisión Nacional de Investigación Científica y Tecnológica - CONICYT

FONDAP CENTERS OF RESEARCH PROGRAM

FINAL REPORT

FIRST FIVE-YEAR PERIOD

Guidelines:

The report should be written following the format specified hereafter. Both a printed (report and excel spreadsheets) and an electronic version must be sent to the following address:

PROGRAMA CENTROS DE EXCELENCIA FONDAP
CONICYT
Moneda 1375, Floor 9
Providencia
Santiago

E-mail: mcamelio@conicyt.cl
Phone: (56 – 2) 2435 43 27

For future inquiries, please contact:

María Eugenia Camelio
FONDAP Program Acting Director
E-mail: mcamelio@conicyt.cl

CONICYT
Ministerio de Educación
Gobierno de Chile

Comisión Nacional de Investigación Científica y Tecnológica – CONICYT

I. PRESENTATION

PERIOD COVERED: From: December 2012 To:May 2017

NAME OF THE CENTER Center for Climate and resilience Research Centro de ciencia del Clima y la Resiliencia		**CODE** 15 11 00 09
DIRECTOR OF THE CENTER Laura Gallardo Klenner	**E-MAIL** laura@dgf.uchile.cl	**SIGNATURE**
DEPUTY DIRECTOR René Garreaud Salazar	**E-MAIL** rgarreau@dgf.uchile.cl	**SIGNATURE**
SPONSORING INSTITUTION Universidad de Chile		
SPONSORING INSTITUTION REPRESENTATIVE Patricio Aceituno, Decano FCFM, Universidad de Chile	**E-MAIL** decanato@ing.uchile.cl	**SIGNATURE**
ASSOCIATED INSTITUTION(S) (if applicable) Universidad de Concepción Universidad Austral de Chile		
CENTER WEBSITE ADDRESS http://www.cr2.cl/		

FACULTAD DE CIENCIAS FISICAS Y MATEMATICAS * DECANO * UNIVERSIDAD DE CHILE

DATE: 07/06/2017

II. EXECUTIVE SUMMARY This section must have a maximum of 5 pages.

The first phase of a center of excellence dedicated to climate and resilience research will soon be completed. To date, significant advances have been made in terms of both knowledge development and the integration of new scientists, including the establishment of a team capable of undertaking disciplinary, interdisciplinary, and transdisciplinary research. This collective effort has transcended the traditional boundaries of academia to influence public discussion and policy. Although the primary focus has remained on Chilean society and territory, our methods and many of our results are of interest worldwide. In this report we highlight key achievements and identify shortcomings, difficulties and opportunities that are being confronted in order to prepare for an anticipated second phase. We then address the key objectives of the center, as proposed in early 2012: Deepen our understanding of the climate system, processes, and impacts throughout Chile, in a holistic manner that confronts the complexities of socio-ecological systems; Strengthen the emerging community of natural and social scientists in Earth System Science in Chile; In collaboration with stakeholders, contribute to the definition of climate change adaptation and mitigation measures building societal resilience.

1. Deepening of understanding, and enabling of science

Our research reflects an evolution from disciplinary questions to more integrative investigations of complex issues. Our first report, in 2013, included 27 mainstream publications, largely resulting from previous research carried over by a small group of our investigators. For 2016, we report 58 publications. For 2017, there are already 24 publications and, in addition to a special issue (in preparation) detailing regional manifestations of the Anthropocene in Chile, and studies addressing the physical mechanisms and societal impacts of the drought experienced in central-southern Chile over nearly seven years. These recent publications are deeply rooted in CR2 research and are often led by younger researchers who have sought to become part of CR2 over the past few years. Furthermore, many of these publications incorporate significant contributions from social scientists, revealing the increasingly ambitious and expanding research team’s efforts to address climate variability, climate change, and social resilience holistically.

In addition to producing peer-reviewed publications, CR2 has enriched political and policy discussions in Chile. First, a “report to the nation” explaining the causes and consequences of the drought was formally received by her Excellency President Michelle Bachelet in November 2015 (CR2, 2015). CR2 also prepared a report to guide national legislation on climate change (Moraga Sariego et al., 2016); preparation involved consultation with the Ministry for the Environment and members of Parliament representing all political sectors.

During the first phase of the center, we organized our work within five lines of research: Biogeochemistry, Climate Dynamics, Ecosystem Services, Human Dimensions, and Modeling and Observing Systems. Each area posed specific questions, which partially converged on integrative themes: water scarcity, land use change, and the effects of urbanization throughout Chile. Highlights of this research are presented in the following section.

Questions by research line

In response to the 19 questions posed between all research lines, we can identify results in the form of peer-reviewed publications, book chapters, theses, databases, and model simulations. New questions have also emerged, often as byproducts of initial, integrative investigations. Below, we present examples of the questions addressed by each research line.

- Within **biogeochemistry**, extensive effort was dedicated to quantifying and characterizing biogeochemical pathways of greenhouse gases to and from the upwelling system. The research team demonstrated that areas of coastal upwelling along northern and central Chile constitute significant sources of greenhouse gases to the atmosphere. The team also found that oxygen-poor subsurface waters favor the accumulation and recycling of nitrous oxide (N_2O) and methane (CH_4), and identified a new biological pathway of N_2O consumption (Farías et al., 2013a; Florez-Leiva et al., 2013; Galán et al., 2014; Pérez et al., 2014; Castro-González and Farías, 2015b; Castro-González et al., 2015; Cornejo et al., 2015; Farías et al., 2015a; Fernández et al., 2015; Carrasco et al., 2017).

- **Climate dynamics** analyses allowed an attribution to anthropogenic forcing of ca. 25% (Boisier et al., 2016) of the drying trend of ca. 10% since 1980 (Jacques-Coper and Garreaud, 2015) observed in central and southern Chile, as well as in the Altiplano (Neukom et al., 2015). This trend has also been contextualized in paleo-records (Masiokas et al., 2016; Munoz et al., 2016) and climate projections, and consequences on water resources and vegetation (Garreaud et al., 2017). Past environmental variability in Patagonia was also analyzed identifying centennial to millennial modes of natural variability (Moreno et al., 2014; Pesce and Moreno, 2014; Henriquez et al., 2015b; Moreno et al., 2015; Stern et al., 2016; Simi et al., 2017). Along the western coast of South America, (Vuille et al., 2015) found a monotonic warming since 1960 at elevations above 1000 m a.s.l. and a cooling along the costal stations since 1980 in contrast with a coastal warming in the previous decades.
- The work of **Ecosystem Services** reveals the rapid loss of native forests from 1975 to 2010, and the consequences of this loss in terms of biodiversity (Miranda et al., 2015; Miranda et al., 2017). Native forests' role in storing carbon, providing water and reducing vulnerability to forest fires gives them advantages when compared to exotic pine and eucalyptus plantations (Little et al., 2015; Urrutia-Jalabert et al., 2015a,b,c). An estimate of the amount and seasonality of the recovery of water provision from the restoration of native forests has been provided (Lara et al., 2013).
- **Human dimensions** focused on the identification of local drought adaptation strategies, applying i.a. the "action-research" paradigm (Urquiza and Cadenas, 2015; Aldunce et al., 2016b). Systematic work addressed theoretical and practical aspects of resilience (Adler et al., 2015; Bórquez et al., 2017). A novel legal conceptualization of climate change damage was proposed to replace the vague understanding of "loss and damage"; climate change damage is understood as residual damage, whether material, moral, or environmental, that might lead to reparation under international public law (Kugler and Moraga Sariego, 2016).
- **Modeling and observing systems** documented climate variability and change using several parameters. Tropospheric ozone climatologies and trends have been analyzed for the remote atmosphere (Gallardo et al., 2016b; Anet et al., 2017), and the analysis of simulations for the last millennium has allowed for the evaluation of fluctuations in the South American Monsoon (Rojas et al., 2016), as well as of long-term climate variations associated with insolation changes and the more recent effects of anthropogenic forcing in southern South America (Berman et al., 2017). The impacts of air pollution on the Andean cryosphere (Molina et al., 2015), and long-term evolution of air quality in urban areas (Barraza et al., 2017) are being systematically measured and simulated.

Integrative questions

The broad issues of water scarcity, land use change, and urbanization were reformulated as integrative questions to provide common frameworks for analysis. First, we addressed water scarcity by looking specifically at the causes and consequences of the drought that has affected central and southern Chile since 2010. Second, acknowledging that the mega drought study required nearly 2.5 years to be completed, we opted to address urbanization and land use changes jointly, as regional manifestations of the Anthropocene.

Mega drought study

The "mega drought" investigation was our first attempt at an interdisciplinary study, and resulted in the previously mentioned "report to the nation" and multiple research articles (Aldunce et al., 2016b; Boisier et al., 2016; Garreaud et al., 2017; Gonzalez et al., 2017; Urrutia-Jalabert et al., 2017a). According to these studies, the drought has no analog in paleo-records for the last 1000 years, and is extraordinary in terms of geographical extension (reaching ~40°S) and temporal extension (of ~6 years). Moreover, approximately 25% of the drought experienced over the last half decade in central and southern Chile cannot be explained by natural variability; i.e., a distinct anthropogenic signal has emerged in rainfall records. The impacts of this drought are not only relevant to water provision for agriculture and human consumption but also to fire regimes and coastal productivity. In general, public and private responses assume that droughts are either extraordinary or short-lasting phenomena. However, future climate scenarios and various climate proxies suggest a progressive aridification of central and south-central Chile due to the increased occurrence of long-term droughts. Together with the multiplicity of authorities (>40) that respond to droughts with an uncoordinated combination of economic subsidies, damn construction, and provision of water trucks, this limited understanding results in suboptimal economic and social responses to the recurrent water shortage projected for coming decades.

Regional manifestations of the Anthropocene: the case of Chile

Regardless of whether we have entered a new geological era, what is being called into question is the paths to development. In a country where social inequalities are so marked, meeting this challenge is of crucial importance and may even be the road to new opportunities. Thus, CR2 has worked some of the regional manifestations of the Anthropocene in Chile, in order to identify paths to greater resilience. CR2 has studied the co-evolution of air quality and the mobility of the residents of Santiago over the last 30 years, including the obvious trends and the need for new public policies based not just on adopting technological advances, but rather on changes in behavior and social transformations. Another CR2 study addressed changes in land use and their consequences on biodiversity, water resources, carbon capture and storage, and fire regimes, and called for comprehensive sustainable management of native forest and forestry plantations. Other authors have studied the causes of the variability of precipitation in Chile's central and southern zones. They have also reviewed the uncertainties implicit in climate projections. These aspects are then taken into account when evaluating the best way to allocate water resources under existing legislation. Changes climate dynamics and their effects on coastal biogeochemical processes are discussed in light of climate projections and empirical evidence. Paleo-geo-historical records are used to analyze human influence in Chile's territory since pre-Hispanic times. Finally, the study of climate change governance in Chile suggests ways for improvement through greater citizen participation and integration. This set of papers has been accepted as a special issue (in preparation) in *Elementa: Science of the Anthropocene.*

2. Enabling science

The 2012 proposal was prepared by a small group (~10) of women and men who shared a passion for understanding climate and social resilience from different specialties and career paths. We then engaged 22 researchers, who added an equivalent of ca. 7.5 full time research positions (44 hours per week). Today, including associate (19), adjoint (17) and post-doctoral (12) researchers, the center incorporates 48 scientists, or 21 full time research positions. An important and distinctive feature of CR2 is gender equality; women make up 46% of all researchers and hold prominent leadership roles, and are authors of 41% of peer-reviewed articles. Additionally, 67 Chilean and foreign researchers have been part of the CR2 team. At the time of this report's preparation, we have accumulated 178 peer-reviewed publications in indexed journals, 10 in non-indexed journals, 34 books and book chapters, and 37 under graduate exams, 47 masters and 7 doctoral theses. These numbers reflect an increasingly productive team, yet it remains a challenge to maintain a critical mass of dedicated scientists with a core of full time positions. Similarly, the efficiency of maintaining a relatively large number of short-term research assistants versus the possibility of training and maintaining "research engineers" requires further evaluation for a second phase.

By combining the CR2 budget, funding from other projects, and contributions from associated institutions, we have acquired instrumentation and infrastructure to enable further research, not only within CR2 but also by other researchers throughout the country. For example, we installed a marine buoy off the coast of Concepción to collect key oceanographic and meteorological data, which are available to the community[1]. Likewise, analytical instruments available at Universidad de Concepción allow for the characterization of water, nitrogen and carbon isotopes. Similarly, we have contributed to the acquisition of a robotic storage facility within the National Laboratory for High-Performance Computing. Other instrumental capacities are materializing in the form of long-term observatories. For instance, we are measuring aerosol optical properties in urban and

[1] http://www.cr2.cl/posar/

background sites as part of the Aerosol Robotic Network[2], and carbon and meteorological fluxes with an eddy flux tower at the *Alerce Costero* National Park[3]. In spring 2017 and in collaboration with other centers and universities and the Ministry for the Environment, we expect to install a high-altitude station measuring meteorological and nival parameters, wet deposition, and aerosol optical depth along three sites in the central Andes at 2300, 2800 and 4000 m a.s.l., downwind from Santiago. A similar initiative is also ongoing in Patagonia.

In addition to these instruments, we have built, recovered, and made broadly accessible numerous databases. An outstanding example of this is the "Climate Explorer"[4], a tool that allows users to visualize, analyze, and download long-term series of temperature, precipitation, and stream-flow. The data are obtained from Chile's Meteorological Office, the General Waters Directorate and the Ministry of the Environment. Other physical data such as emission fluxes, climate simulations and projections, as well as economic and social data, are being collected to be similarly integrated and presented.

3. Team building for interdisciplinary research

Any complex problem, and particularly an Earth System functioning in no-analogue mode, requires action not only to mitigate the drivers of dangerous climate change and enhance societal resilience, but also to shift scientific paradigm from the traditional disciplinary model towards an integrative approach. A great deal of effort was therefore directed toward the unique challenge of building an interdisciplinary research team in Chile. We understood early on that this was a difficult process for which we were to make our own path albeit looking for experiences from elsewhere.

In addition to conciliating multiple and diverse disciplinary backgrounds, academic trajectories and seniority levels, and institutional frameworks, we faced the challenge of the physical distance between researchers located throughout Chile. In response, we organized two meetings each year for our entire team and, whenever possible, our national and international advisory panels. Individual research groups also integrated multiple disciplines and backgrounds and therefore required additional effort to find common ground, particularly in the case of Human Dimensions and Biogeochemistry. The Modeling and Observing Systems and Human Dimensions groups were implicitly expected to simultaneously develop research and provide support to other research lines, an expectation which was not entirely fulfilled. Ecosystem Services and Climate Dynamics were to some extent limited in their integration with other research areas.

To speed up exchange among researchers and the formulation of common questions, we applied group dynamics techniques based primarily on in-house knowledge provided by social scientists or externally-hired facilitators. These activities often left too little time for actual scientific discussion, a deficit we moderated somewhat by incorporating short talks and poster presentations. Additional, smaller team meetings and visits were also coordinated.

We carried out a diagnosis in late 2016 to describe and analyze the organizational model of CR2 (Urquiza and Morales, 2017). Strategic definitions of CR2 identified by its members include: Knowledge generation, Interdiscipline, and Science-society relationships. CR2 members show a transversally high commitment and sense of belonging to CR2. Criticism identified a lack of explicit protocols for membership, roles and functions, particularly among students and adjoint researchers. Another important output of this study was the general consensus on re-structuring CR2 around common topics or interdisciplinary problems to better enable interdisciplinary research and overcome the natural-social sciences dichotomy.

4. Networking and outreach

Despite politically differentiated government administrations, we have sustained connections and collaboration with the Ministry of the Environment, the Ministry of Foreign Affairs, the Ministry of Public Works, and the Ministry of Economy, as well as with other offices including the Chilean Weather Office and Chilean Emergency Office. This collaboration has taken the form of concurrent projects in which our researchers or the center as a whole have participated (e.g., New climate

[2] https://aeronet.gsfc.nasa.gov/new_web/photo_db/Santiago_Beauchef_2.html
[3] https://fluxnet.ornl.gov/site/2900
[4] http://explorador.cr2.cl/ Nowadays, its counts with more than 1000 visits per month

projections for Chile; Analysis of the Atacama floods; Chilean Climate Law; National Climate Action Plan; Third National Communication on Climate Change, etc.). CR2 has been a part of the Chilean delegation to the Conferences of the Parties to the United Nations Framework Convention on Climate Change, in Lima (COP 20), Paris (COP21), and Marrakech (COP22), and our researchers have been invited to participate in ministerial and presidential commissions (Air Quality, Disaster Management and Prevention, Energy, Water Resources, Fires, Algal Blooms, etc.).

Collaboration has extended to other centers of excellence in Chile, including the Center for Mathematical Modeling (CMM), the Institute of Ecology and Biodiversity (IEB), Solar Energy Research Center (SERC), the Andean Geothermal Center of Excellence (CEGA), the Center for Integrated Natural Disaster Management (CIGIDEN), the Center for Sustainable Urban Development (CEDEUS), the Research Center: Dynamics of High Latitude Marine Ecosystems (IDEAL), etc., as well as to university centers and programs such as the Program for Risk Reduction and Natural Disasters (CITRID) and the Energy Center (CE) at the University of Chile, the Institute for Complex Engineering Systems (ISCI), and the Center for Global Change (CCG) at the Catholic University. These collaborations have produced co-authorship of papers and reports, shared researchers (CMM, SERC, IDEAL, ISCI), and joint projects (CEGA, IEB, SERC, CE, CCG). We expect to strengthen these connections during a second phase with, for example, the establishment of long-term observatories.

Many of our publications demonstrate the strong presence of our researchers on five continents. More importantly, CR2 has gained international presence beyond the connections of individual researchers or specific projects. For example, in addition the Southern Hemisphere Meteorology and Oceanography Conference held in Santiago in 2015, international conferences including the Global Emissions InitiAtive (GEIA), the Transformations Conference, and the Forest and Water Conference, have requested our co-sponsorship as host for these meetings in Chile, beginning in 2018. Furthermore, since the COP22 in Marrakech, CR2 belongs to an international consortium of centers of excellence intended to promote capacity building and to explore means to monitor the Paris Agreement over coming years (INCETT). Work remains for CR2 to further establish an international presence and to gain recognition as a regional research hub. To this end, in addition to participating in regional and global research endeavors, it is key to strengthen post-graduate programs and offer improved post-doctoral and research positions, and seasonal schools.

Along with scientific research, outreach to the non-expert public is a fundamental part of CR2's mission and activities. The center aims to raise awareness and understanding of climate change and variability and the impacts of each in Chile. Instrumental to this endeavor have been highly skilled and motivated journalists, and the willingness of many researchers to communicate science. As of March 2017, we had accumulated 716 media appearances in newspapers and on radio or television, including several in international media. We expect to expand our media coverage and website and social media presence by improving the English sections, and by augmenting the presence of videos and data interfaces, as well as with regular media training of CR2 researchers and students. Our communications' team is small and works with relatively limited resources. Nevertheless, the team has managed to explore new venues such as art expositions, poetry, and capacity building and with science communicators in other centers (CEGA, IEB) and has led to successful and satisfying experiences like "Julieta in the Land of Girls"[5].

Adjustments regarding CR2's structure, methodologies, and research questions and foci are already ongoing. These changes make us confident in improving our performance and functioning. All in all, we believe that CR2 is ready for a second phase driven by more ambitious goals and seeking to further contribute to understanding and addressing climate variability and change in order to create a more resilient Chile.

---

[5] http://www.julietaexploradora.cl/ This project in particular received the 2016 Innovation in Scientific Education prize awarded jointly by the Young Science Foundation and United Nations Educational, Scientific and Cultural Organization (UNESCO) to the best informal scientific education project, an acknowledgement of its contribution to narrowing the gender gap in Chilean science.

III. RESULTS:

1. Research: the most relevant scientific achievements of the Center must be summarized in a maximum of 15 pages.

Integrative questions

Mega drought

Here we present the main findings of the "Central Chile Mega Drought (MD)" study. This study has resulted in a "report to the nation" (CR2, 2015) and in multiple peer-reviewed articles either already published (Aldunce et al., 2016b; Boisier et al., 2016; Garreaud et al., 2017) or in review (Aldunce et al., 2017a; Aldunce et al., 2017b; Gonzalez et al., 2017; Urrutia-Jalabert et al., 2017a), various conference proceedings and numerous seminars for the science community and the general public.

Crowning the drying trend observed in central Chile since the late 70s (Jacques-Coper and Garreaud, 2015), a dry spell has afflicted this region since 2010. The MD has been the longest multiannual dry period in the instrumental record, and their consequences are readily discernible in surface and underground water reservoirs, snowpack, and river exportation of nutrients into the ocean and forest fires (Yevenes et al., 2016a; Garreaud et al., 2017; Gonzalez et al., 2017). The MD is unprecedented in the historical record. Moreover, a tree-ring (*Austrocedrus Chilensis*) based reconstruction of central Chile precipitation developed by D. Christie and colleagues (Álvarez et al., 2015; Garreaud et al., 2017) indicates that the current MD only has 1 or 2 analogues in the last 1000 years and it emerges as an extreme event in a drying trend initiated about a century ago.

The years that compose the MD have featured near neutral El Niño Southern Oscillation (ENSO) conditions in the equatorial Pacific but the Pacific Decadal Oscillation (PDO) has been in its negative (cold) phase that favors dry conditions in central Chile. Nonetheless, the recent work by (Boisier et al., 2016) has proven that anthropogenic climate change explains at least a quarter of the longevity and intensity of the MD. The attribution of part of the MD to anthropogenic climate change is a major scientific finding with important societal implications (Pino et al., 2015; Aldunce et al., 2016b; Aldunce et al., 2017a, b)

The ~30% precipitation deficit found at low-level stations in Central Chile also affected the subtropical Andes snowpack, leading to a concomitant decline in annual mean river flow across the highly populated Central Chile as well as the agricultural region of Argentina adjacent to the Andes. The drought propagation through the hydrological cycle resulted in the amplification of the MD-mean signal, especially to the north of Santiago. The MD also set the stage for enhanced fire activity in central Chile and decrease in coastal productivity.

In general, governmental and private responses assume that droughts are either extraordinary or short-lasting phenomena. However, future climate scenarios and various climate proxies suggest a progressive aridification of central and south-central Chile due to the increased occurrence of protracted events as the MD. This, and the existence of a multiplicity of authorities (>40) that respond to droughts, typically via economical subsidies, building damns, deepening wells, and providing water trucks in a rather discoordinated manner result in suboptimal economic and social responses, which are no longer appropriate to address the recurrent water shortage Chile will be facing over the next decades.

Regional manifestations of the Anthropocene in Chile

In a way, the Anthropocene altered the development path of Chile in the late XIX century. In fact, the energy intensive Haber-Bosch process that permitted the synthesis of ammonia clashed the early economic development of Chile based on natural nitrate or salt-peter. It is also blamed for have given rise to the population explosion. In the XXI century, Chile's development is at stake because of the threats posed by natural variability and anthropogenic climate change in a society crossed by inequities and vulnerabilities. It also offers an opportunity to propel a sustainable development based on renewable energy and a resilient society able to cope, adapt and change to face our changing climate. As the world at large, in Chile one finds multiple geo-historical records of large-scale perturbations of the natural environment that identify the emergence of a new geological era. Also, accelerated urbanization and land use changes, in addition to distinct anthropogenic disturbances on climate that result in drying and warming trends where ca. 90% of the population concentrates, as well as on the Chile-Peru upwelling system, pose challenges to the country's sustainability. Still, opportunities and ways forward also appear. The analysis of the many challenges and opportunities at stake for Chile, constitute relevant information for other countries in the region and elsewhere in the world to face the new epoch. With this in mind, we have been working on a set of articles highlighting regional manifestations of the Anthropocene in Chile, and synthesizing science and policy relevant information.

The drivers of the Anthropocene act locally and regionally, and so do the manifestations of multiple adverse impacts. Thus, in order to adopt adequate and robust mitigation actions, local and regional aspects must be addressed and better understood. In this set of articles, we synthesize geo-historical records collected in Chile [Gayó et al, in progress], which reveal an early in set of significant environmental perturbations by humans. Further, we describe records of changes in some socio-ecosystems that show a distinct and accelerated human disturbance since the mid-20th century. In particular, we address human disturbances on water availability and watersheds [Boisier et al, in preparation], air quality in urban areas [Gallardo et al, in preparation], the Peru-Chile upwelling system [Aguirre et al, in preparation], and forest landscapes [Lara et al, in preparation]. Moreover, we look into the sustainability of our water allocation rules in face of climate variability and change [Barría et al, in preparation].Finally, we explore to what extent our climate change governance allows a polycentric approach [Arriagada et al, in preparation]. When known, we describe the driving processes for the observed changes, and project future scenarios. Also, we examine key knowledge gaps. These papers are being finalized for submission in early July to a special issue/section in Elementa: Science of the Anthropocene. A list of papers follows:

- Aguirre et al, Some insights about anthropogenic forcing on coastal upwelling off central and -southern Chile
- Arriagada et al, Governing climate change in the Anthropocene: modes of governance and steps towards polycentrism in Chile
- Barría et al, Anthropocene and streamflow: long-term perspective of streamflow variability and water rights
- Boisier et al, Long-term precipitation and streamflow variability in Chile over the last 50 years
- Gallardo et al, Evolution of Santiago's air quality: the role of mobility and lessons from the science-policy interface
- Gayó et al, Geo-historical records of the Anthropocene in Chile
- Lara et al, The impacts of land use change on biodiversity and forest ecosystem services during the Anthropocene in Chile

All papers contain policy relevant information, and synthesize CR2 research. In a couple of papers, there are contributions from policy makers.

Research lines

Biogeochemistry

The biogeochemistry (BGQ) group includes specialists in, among other disciplines, oceanography, atmospheric science, biology, microbiology, paleo-ecology, and archaeology. These disciplines converge into a common goal, that is to investigate the exchange and transformation of elements and compounds, such as water, greenhouse gases (CO_2, CH_4, N_2O) and bio elements (nutrients and trace elements), between different compartments of the Earth System: atmosphere, hydrosphere (ocean), lithosphere, and biosphere (explicitly incorporating humans societies). In practice our group has been investigating all of these topics throughout the extraordinary diversity of marine and terrestrial environments of Chile: from the arid Atacama Desert to the Antarctic Peninsula. We have addressed emissions and traceability of greenhouse gases and other extremely powerful radiative compounds, in order to determine the influence of natural versus anthropogenic factors as forcing-agents of Climate Change. The projected warming alongside with other associated transformations (changes in land-use and urbanization) and extreme climatic events could certainly affect water availability and quality, as well as other environmental elements. Thus, there is a pressing need to fully understand and predict the real extent for such issues in order to develop societal strategies for adapting and mitigating their effects. In this manner, the BGQ group has focused on several topics, including; characterizing extreme climatic events (e.g. mega droughts) at different spatial-temporal scales, changes in soil use and consequences on the transport of nutrients and sediments, urban aerosol emissions, and social resilience to environmental variability. Hence, our group has actively contributed to tackle core and transversal issues of the CR2.

Greenhouse gas emissions and recycling in the ocean

The BGQ group addresses the role of the ocean in the emissions and sequestration of greenhouse gases, aerosols and other compounds. There are several systems within the Eastern South Pacific (ESP) with distinguishing oceanographic features, such as coastal upwelling, fjords and estuaries, subtropical gyres, among others. Coastal upwelling areas, such as those in northern and central Chile, are known to contribute significant quantities of gas into the atmosphere, up to 10 orders of magnitude higher than those estimated in neighboring areas, such as the subtropical gyre (Farías et al., 2015b).

This extent of magnitude depends on the trophic state of each system in terms of its phytoplankton biomass (eutrophic vs. oligotrophic), which is regulated by circulation, dynamic processes and water masses. It is noted that if an oxygen minimum zone is present in association with sub-surface water, is able to stimulate the recycling and accumulation of N_2O and CH_4. On the other hand, the fjords and estuaries in the southern central zone do not contribute significant levels of N_2O to the atmosphere (Yevenes et al., 2016b). This may be a reflection on the lack of anthropogenic intervention over this area, as there is practically zero nitrogen addition from agriculture activities. Nevertheless, these zones act as a CH_4 source, partly due to terrestrial inputs that reach the marine system from continental runoff (Farías et al., 2017).

Traceability in biogeochemical processes and main microbial actors

In addition to quantifying greenhouse gas exchange, biogeochemical processes that recycle these gases have been analyzed through, i.a., observing the distribution of stable isotopes. The BGC group has made major contributions to this area of research through the detection of new biogeochemical pathways and their potential microbial actors (Farías et al., 2013b). In this respect, it has been reported that part of the surface CH_4 is produced by the cleavage and cycling of dimethyl sulfide, a biogenic compound only generated in the ocean, and a precursor of aerosols (Florez-Leiva et al., 2013).This partly explains the methane paradox, i.e. that the gas apparently existed in oxygenated areas until recently, however was reported to be only produced through anaerobic processes (i.e. only in areas with minimal oxygen, and in sediments or soils)

Regarding N_2O, a new consumption mechanism has been reported for this gas within the ocean. Thus far, the dissimilative reduction of N_2O is the only process known to be capable of consuming this gas, however chemical and biological evidence exists that some diazotrophic organisms can fix N_2 using the enzyme nitrogenase, that is also able to use N_2O (Farías et al., 2013b).This is an ubiquitous process that is responsible for certain areas of the ocean acting as a N_2O sink (Cornejo et al., 2015). This mechanism would help reducing uncertainties around the nitrogen balance in the ocean, as well as globally. Finally, due to the suboxic and anoxic conditions in the region, biogeochemical and molecular knowledge has been developed on anaerobic microorganisms that mediate processes such as denitrification and methanogenesis (Galán et al., 2014; Castro-González and Farías, 2015a).

The melting of continental glaciers and sea ice has triggered the study of biogeochemical processes in the Antarctic Peninsula and Arctic Ocean under scenarios of salinity reduction and warming (Moreno-Pino et al., 2016; Verdugo et al., 2016). Results indicate that salinity reduction together with other environmental changes promote marine microbial communities variations that in turn might explain different pathways of C and N recycling. These studies have also extended into the Arctic Ocean.

The BGQ has analyzed ^{14}C concentrations in the Queñua Highlands (*Polylepis tarapacana*), the Chilean Cypress trees in the central Andes (*Austrocedrus chilensis*), the Redwood trees in the Valdivian Rainforest (*Fitzroya cupressoides*) and the Guaitecas Cypress trees in the sub Antarctic forests of the Strait of Magellan (Pilgerodendron uviferum) [De Pol-Holz et al, in preparation]. Thus, it is possible to develop a new understanding on how the atmosphere is either younger or older according to the intensity of CO_2 exchange in the Southern Ocean. We observe that gas exchange with the Southern Ocean is the main mechanism ageing the atmosphere. Currently, the oldest waters on Earth (according to radiocarbons) are about 2300 years old and found deep in the Pacific Ocean (Siani et al., 2013; Ronge et al., 2016). However, evidence from radiocarbon studies in foraminifera show that during the Ice Age (18,000 years ago), deep Pacific waters were much older. In fact, the age difference with the atmosphere exceeded 6000 years. A conceptual model is used to explain this discrepancy. The model involves a minimum in CO_2 exchange between the Southern Ocean and the Southern Hemisphere atmosphere, along with high volcanic activity in the submerged ridges of the Pacific Ocean. Both processes "age" the waters as no ^{14}C atoms are gained from the atmosphere (and remaining atoms are lost through radioactive decay), and additionally the volcanos dilute the remaining ^{14}C atoms by supplying million year old CO_2 which will have lost all the ^{14}C radioactively. In the meantime, all these analyses have been functional to the understanding of climate variability and its consequences in oceanic and terrestrial ecosystems (Martínez-Méndez et al., 2013; Moreno et al., 2014; Ugalde et al., 2015; Stern et al., 2016).

Variability in liquid water content in the cloud forests of Northern Chile

An observational site in the coastal area of Talinay some 500 km north of Santiago has been deployed. At this site, in addition to meteorological parameters, including occasional soundings, liquid water content associated with the cloud forests are been measured [Rondanelli, in preparation]. The liquid water content is significant, as the composition and distribution of droplet size determines the extent of radiation reflected back into space, and ultimately the amount of radiation reaching the earth's surface. The formation rates for different types of precipitation, in particular warm precipitation, are critically dependent on the liquid water content. The liquid water content and drop size distribution are also used to understand the persistence of natural forests on the slopes of this semi-arid region, around 30ºS, where precipitation is just under 200mm per year. The geometry of the coastal topography, as well as the cloudiness, encourages the existence of these forests that provide a unique opportunity for in-situ observation of cloud properties, as well as a source of drinkable water in a semi-arid region.

Biogeochemical impacts of the Mega drought

The impact of the mega drought on phytoplankton biomass under the actual climate change scenario in coastal areas of Central Chile has been studied for the last two decades focusing in a drought period 2010-2014. To do that variability of the rivers discharge, plume signature and phytoplankton biomass were studied in the influenced coastal area of 5 rivers (Maipo, Mataquito, Maule, Itata and Bio Bio) using 15 years (2000-2014) of satellite data and water discharges observations [Masotti et al, in preparation]. Variability of river discharge modifies directly the plume river extension with consequences on the phytoplankton biomass. All rivers discharge and plume extension were reduced (38% to 57%; 34% to 58%, respectively) during the mega drought with a major impact on the phytoplankton biomass (11% to 14% decrease) in the Maipo and Mataquito rivers. Additionally, the drought also impacted the nitrate reducing it in 45%, 46%, 59% and 21%, for Maipo, Mataquito, Itata and Bio Bio rivers respectively, during the drought period with respect to the period 2000-2010 (Yevenes et al., 2016a). The decline in water quality during summer droughts is due to limited dilution of the chemical load. Nitrate sources from river waters derive from three main origins; soil N, fertilizers from agricultural activities, manure or septic systems and other inputs that can be nitrified in the river or land. High-resolution water leaching and runoff maps allowed us to identify agriculture areas with major probability of water leaching and higher probability of runoff in silviculture areas (Yevenes et al., 2016a). An analysis of how these river influenced coastal ecosystems are sensible to changes in river discharge usually controlled by natural (e.g. rainfall, snow) and anthropogenic factors (e.g. change in land-use, river water demand) were done.

Resilience of pre-Hispanic societies to environmental changes

We worked on the understanding of the feedback relationship between pre-Hispanic societies and environmental changes, which could provide important tools for the mid and long-term territorial, socio-political, and development planning of Chile. We have been investigating the impact of past variations in the hydrological cycle and ocean circulation on pre-Columbian societies that have inhabited the inland, coastal and oceanic Chile over the past 14,000 years (Valenzuela et al., 2015; Santoro et al., 2016a; Flores-Fernandez et al., 2017; Gayo et al., 2017; Joly et al., 2017; Latorre et al., 2017; Osorio et al., 2017). This task involves an integrated study of archaeological and paleo environmental records, using diverse biogeochemical approaches (e.g., stable isotopes, radiocarbon dating, development/exploration of databases) (Ugalde et al., 2015). Our results suggest that paleoclimate defined spatial-temporal dynamics and structure of regional pre-Hispanic societies. For example, we found that the early colonization of South America involved this area, closely tied to variations in the availability of biotic and hydrological resources on a regional-scale (Santoro et al., 2016b). An innovative long-term reconstruction of demographic history over the past 14,000 years shows how variations in bio productivity moderated the intensity of activities, and influenced decisions in pre-Columbian societies (Gayo et al., 2015). Actually, marked oscillations in the population levels of both hunter-gatherer groups and agricultural societies are evident (Gayo et al., 2016). In general, demographic declines (growths) occurred during prolonged droughts (pluvial stages) (Gayo et al., 2016). These climate-driven demographic processes were accompanied by spatial rearrangements of human populations across different environments and led to diverse adaptative strategies (i.e., cultural and technological solutions). In addition to the understanding of human-climate dependencies in history, these studies bring insights for the understanding and setting of the Anthropocene in Chile [Gayó et al, in preparation].

Other contributions

Associated to this research line, one also find several other key-contributions in explaining extreme events such as the mega drought or the damaging flooding registered in March 2015 in the Atacama Desert (Barrett et al., 2016; Boisier et al., 2016; Bozkurt et al., 2016a; Bozkurt et al., 2016b). Likewise, collaborations appear in terms of urban pollution and its downwind impacts (Escribano et al., 2014; Cordova et al., 2016), tropospheric ozone (Seguel et al., 2013; Gallardo et al., 2016a), and quantification of solar radiation in northern Chile (Kerber et al., 2014; Rondanelli et al., 2015; Cordero et al., 2016), i.e., perhaps the key-energy source for Chile's future development.

The biogeochemistry team has been essential to the deployment of key-instrumentation including the oceanic buoy, the wet deposition sampler, the isotope analysis system, the fog instrument, the sunphotometer, as well as the development of low-cost sensors for solar radiation and aerosols [Rondanelli et al, in preparation].

Climate Dynamics

The Climate Dynamics (CD) group consists of 3 senior researchers, and some 10 adjoint researchers, post-docs and graduate students. Although relatively small in terms of number of researchers, CD is in the core of the CR2 and it has conducted both disciplinary and interdisciplinary research as described in this section. Our group has also been heavily involved in three major transversal initiatives of CR2: the assembly of climate datasets, the development of the Climate Explorer, and the establishment and operation of POSAR, a met/ocean coastal buoy in the Bio Bio region. Likewise, members of CD actively engaged in science communication and outreach.

Broadly speaking, the CD research is organized in two major areas: current and near future climate dynamics, and past environmental variability. The first area is addressed by using historical records as well as model simulations, aiming at the description, diagnosis and attribution of contemporaneous climate fluctuations in time scales from year to decades. The second area is addressed using several paleo-records and their respective calibration and analysis techniques. Tree rings of selected species and locations provide a high-resolution (annual) context of hydroclimate (rainfall, river flow, snowpack) variations during most part of the last millennium. On the other hand, sediment cores taken from small lakes in southern Chile provides a depiction of low-frequency (decades to century) environmental variability as far back as the Last Glacial Maximum (LGM, ca 18.000 years ago).

Indeed, the research areas described before have been cultivated by the CD members well before the establishment of CR2. In the center, however, we have teamed together around an overarching theme, namely, disentangling the contributions of natural and anthropogenic forcing of climate anomalies and trends observed in current climate across our country and, more generally, in southern South America. This is a major task and a fundamental step if one pretends to make useful prediction about the regional environmental future during the 21st century. Particular emphasis has been placed in hydrological resources, as our country still bases its economic growth in the exploitation of natural resources and water is much required in agriculture, mining and hydro-power, as well as for human consumption. Moreover, large portions of Chile already face water scarcity and are afflicted by hydro-meteorological extremes. Advances in this overarching theme has been partially accomplished on the basis of specific research initiatives whose main results are described in the following.

Precipitation variability and trends

El Niño Southern Oscillation (ENSO) is a major planetary-scale phenomenon of natural origin and existent in the climate systems since, at least, the early Holocene, with major climate implications. For instance, during El Niño years there is summertime precipitation deficit in the Altiplano (northern Chile), above average winter precipitation in the Mediterranean sector (30º-38ºS) and a tendency for less precipitation during summer in austral Chile. In this context, a major results has been the reconstruction of ENSO variability (i.e., the typical amplitude of El Niño – La Niña events in the equatorial Pacific) using tree rings records from dozen of locations worldwide (Li et al., 2013). This reconstruction shows a significant increment in the level of variability in during the 20th century compared with last 700 years.

The strong ENSO signal in the rainfall variability in central Chile somewhat obscured any trend in the observational record during the last century. Updated analyses, however, have allowed to detect a regional drying trend of about 10% per decade since the late 1970s. About half of this trend is induced by changes in the polarity of the Pacific Decadal Oscillation (PDO), another natural mode akin to ENSO (Jacques-Coper and Garreaud, 2015). The rest of the trend, however, was attributed to the anthropogenic climate change (increase in GEI concentrations and stratospheric ozone depletion), one of the major findings of the CD group recently reported by (Boisier et al., 2016). This drying trend is expected to continue in the future leading to an aridification of central Chile. Under a pessimistic greenhouse emissions scenario, central Chile (30-40S) rainfall and river flow are expected to decrease between 25-35% relative to current values toward the end of this century (Bozkurt et al.), an information of high relevance for planning Chile’s future.

Likewise, using climate models, ice-cores and tree-ring records we have found a drying trend over the South American Altiplano since the mid-20th century. Such trend will continue in the 21st century posing a major threat for this semiarid region (Neukom et al., 2015). The observed and projected precipitation deficit will have perceptible impacts in the regional ecosystem and social system, including a sharp decrease in human population (Lima et al., 2016) and a reduction in the forest coverage (Cuyckens et al., 2016).

Temperature trends

Many stations along central Chile have reached historical maxima temperature, both in summer and winter, and we found a warming trend of about 0.2ºC/decade since the late 1970s. The warming trend is much less marked along the coast of subtropical South America and a previous study found a coastal cooling. The coastal cooling seems at odds with the concept of global warming, prompting a more detailed analysis presented in (Vuille et al., 2015) on the basis of updated records of more than 200 stations in western South America. It was found a monotonic warming (at least since 1960) at elevations above 1000 m ASL but they confirmed a cooling along the costal stations since 1980 in contrast with a coastal warming in the previous decades. The change from coastal warming to cooling took place around 1977 and coincided with the climate shift reported, by among others (Jacques-Coper and Garreaud, 2015). Temperature trends in southern Chile are mostly insignificant.

(Vuille et al., 2015) attributed most of the coastal cooling to the Pacific Decadal Oscillation (PDO) cold phase from the early 80’s until about 2015. At least a part of the surface ocean cooling could be explained by the strengthening and expansion of the South Pacific subtropical high, a feature associated with climate change and that will continue in the future (Van den Hoof and Lambert, 2016). It remains to be seen when the locally-forced coastal cooling will be offset by the generalized ocean warming, a question of high scientific and practical relevance.

A look into the deep past

The most recent 3000 years, commonly referred to as the Late Holocene, provide an adequate interval to study centennial-scale fluctuations in global climate, including the most recent warming since the mid-19th century associated with globalization and the Industrial Revolution. Sedimentary records from fast sediment-accumulating, small closed-basin lakes yield ideal material for developing time series of vegetation and fire-regime shifts, allowing detailed examination of past environmental changes at spatial scales of a few hectares to square kilometers surrounding the site, with time resolution ranging from decadal to millennial timescales. The centennial and millennial-scale response of temperate rainforests from southern Chile to natural (climate change, disturbance) and direct (vegetation disturbance) or indirect (atmospheric circulation changes) human perturbations near the forest-steppe ecotone of central Chilean Patagonia, however, has not been addressed in sufficient detail. Knowledge from this area will help identify the timing, direction and magnitude of past changes in atmospheric circulation at regional and zonal scale in the southern mid-latitudes.

We set out to examine the natural ranges of vegetation and climate variability over the last ~3000 years in the Puerto Montt (Jara and Moreno, 2014), Coyhaique (Pesce and Moreno, 2014) and Puerto Natales sectors of Chilean Patagonia [Moreno et al. 2014], detect the onset of Chilean-European disturbance of the landscape, and compare the magnitude and rapidity of human-set changes in reference to natural environmental change. For that purpose we developed detailed pollen and charcoal records from lake sediment cores. Our results show the onset and intensification of centennial-scale variability in SW and NW Patagonia at 5800 and 4600 cal yr BP, respectively. We detect warm/dry SAM-positive-like events (CCs) lasting 200±60 years alternated with 500±200 year-long cold/wet SAM-negative-like phases over the last 11,000 years (Moreno et al., 2014). The most recent SAM-positive-like warm/dry events correspond in timing with the Medieval Climate Anomaly and the Anthropocene separated by an extended cold/wet SAM-negative-like interval, contemporaneous with the Little Ice Age. This correspondence in timing and direction of climate change with Northern Hemisphere records suggests interhemispheric correlation of centennial-scale events over the last millennium, apparently mediated through meridional changes in the SWW.

Other contributions

The impact of the topography on the precipitation and temperature fields in southern Chile has been the subject of research reported in (Minder et al., 2015; Viale and Garreaud, 2015). In the same line, the impact of sea surface temperatures off the Chilean coast upon inland precipitation has been documented in case and climatological studies (Bozkurt et al., 2016b).

Major forest fires have increased significantly during the MD. When close to urban areas, these fires can affect negatively the air quality of these cities, as dramatically observed in Santiago (the Chilean capital) in January 2013 and documented in (Rubio et al., 2015). The installation of a wind profiler just to the west of Santiago will allow to quantify the pollutants transport with more detail[6].

In collaboration with other CR2 members, we have begun to understand the dynamics of extreme hydro meteorological extremes, a fundamental step to project them in the future. In central Chile, warm storms can lead to landslides and flooding even if the precipitation is not extreme, because an upward trend of the freezing level substantially increase the area that receive rainfall and feed the surface runoff. It turns out that such warm storms exhibit distinct features than the more common cold storms and are often associated with Atmospheric Rivers (Garreaud, 2013). We also found that major storms in the Atacama region (usually extremely dry) do occur when the adjacent Pacific is anomalously warm, adding water vapor to the local atmosphere (Bozkurt et al., 2016a; Bozkurt et al., 2016b).

Given the intensive use of observational datasets, the CD group has been a driving force of the CR2's Climate Explorer. More recently, a gridded precipitation dataset on the basis of the quality-controlled station-based rainfall records was created [Boisier et al, in preparation]. This product is available from 1979 onwards on a ~5x5 km^2 grid. The gridded version was created merging statistical downscaling and interpolation techniques. The statistical downscaling builds on multivariate precipitation functions depending on large-scale atmospheric conditions (e.g., precipitation and column-integrated water vapor fluxes) and local topography.

Ecosystem Services

This team has three senior researchers, three adjoint researchers, three post-docs and four Ph.D. students. It stems from an established group with expertise in dendrochronology, ecology, ecological restoration, hydrology and remote sensing. Their work has focused on mapping, quantifying and explaining land use changes in central and southern Chile, and its impacts on ecosystem services, mainly water provision. It has done disciplinary and interdisciplinary research. Researchers from ECO have been actively committed with the development of policy recommendations as well as in the communication of science and outreach to various audiences.

Land Use/Land cover change

The rapid loss of native forests between 1975 and 2011 has been documented (Miranda et al., 2015; Miranda et al., 2017). This latter work showed the loss of 782.120 hectares of native forests between 1973 and 2011, corresponding to 19% of the initial area covered by forests in this period, and to 36.5 % of the area encompassed between Valparaíso (~33°S) and Los Lagos Regions (~40°S). The highest forest loss rates were observed in the decades of 1970 through 1990. Later, it decreased in the 1990-2000 period to regrow between 2000 and 2010. Approximately 45% of total forest loss might be explained by their conversion to shrub lands, followed by pine and eucalypt exotic plantations, agriculture land and pastureland.

Another important progress was the contribution to the development of a methodology for land use/land cover change (LULC) mapping for the entire country, integrating satellite images from various dates and seasons between 2013 and 2014 (Zhao et al., 2016). The method used rendered 80% of accuracy for the map covering Continental Chile. This new methodology sets the guidelines and standards for future studies of LULC in Chile.

Design of Landscapes for the combined provision of goods and ecosystem services

The relationship between forests and water in South America has been studied (Jones et al., 2017). This paper proposes a hypothetical curve with a negative slope for the analysis of the trade-offs between ecosystem services (e.g., water provision) and timber production. If the curve is a

[6] http://www.cr2.cl/recursos-y-publicaciones/laboratorios/mediciones-sodar/

straight line, the increase of water is proportional to the reduction in timber production. Nevertheless, there is a much favorable scenario that is if the curve is convex towards the origin. In this case, important increases in water supply may be obtained with relatively smaller reductions in timber production. This might be obtained through an adequate proportion of native forests and exotic forest plantations in a watershed, proper species selection, rotations and management schemes for the plantations.

Trade-offs between water provision as an ecosystem service and timber production in two watersheds of c. 2,300 hectares in the Maule Region (Agua Fría and Nirivilo) were presented in the Latin American Congress on Landscape Ecology organized in Temuco in November 2016 (This work is done in collaboration with Modeling and Observing Systems). The study documented that if native forest were restored in buffers along streams and rivers (10 to 60 meters wide), assuming that mean annual precipitations remain unvaried, there would be an increase in water provision that is proportional to the buffer width that was restored. This compared with not doing the restoration and maintaining the buffer strip covered with forest plantations (business as usual scenario, BAU), during the next 40 years. Nevertheless, if we consider a gradual decrease in annual precipitations associated to climate change, reaching 40% of decrease for 2071-2100, water provision as an ecosystem service would decrease dramatically for the BAU scenario, and would reduce the potential gains due to forest restoration.

Restoration of native forests using multi-criteria Analysis

We developed a method for prioritization of areas of native forests to be restored in Los Rios Region based on multi-criteria analysis, integrating ecologic, social and economic variables and Geographic Information Systems (GIS). The areas of native forests that have been degraded or destroyed that were defined with high restoration priority resulted from cells in the GIS covers with high scores in ecologic suitability, defined as the capacity to maintain certain level of biodiversity and ecosystem services, and high score in socio-economic feasibility to accomplish the goals of the restoration (Zamorano-Elgueta et al., 2017). This methodology that produces a map of ranked priorities may be applied to various contexts, regions, and stakeholders is valuable to support decision-making for the design of restoration policies and plans. The method may be modified to incorporate different levels of participation in its various stages.

Land use/land cover, drought and other factors affecting wildfire occurrence

We assessed the relative importance of the various anthropogenic and natural factors over fire occurrence in Central and South Central Chile. Human impact, drought, and exotic forest plantations had the main positive and direct effect over the number of fires. On the other hand, areas with a broad cover of native forests showed a negative correlation with fire occurrence [Gómez-González et al, in preparation].

We documented in the chapter on Native Forests within the Report to the Nation on the Environment that the burned area of exotic forest plantations between 1986-1995 and 2006-2015 has increased by 140% (2.4 times), due to their higher flammability (Lara et al., 2016). Conversely, the area covered by native forests and shrub lands that has been burned in the same period was reduced by 10%.

In another publication, we explored plant evolutionary mechanisms related to fire. We found that heat and smoke produce evolutionary changes in the pubescence and shape of *Helenium aromaticum seeds*, a native herbaceous plant from Central Chile (Gómez-González et al., 2016). We also studied the ecological processes that explain the competitive success of invasive plants, a component of global change. For this we compared the invasive *Centaurea melitensis* (Europe) with *Helenium aromaticum* (Sotes et al., 2017).

We studied the relationship between wildfires (number and area burned) with climate variability in Central and South-Central Chile (32°-43°S) for the 1976-2013 period (Urrutia-Jalabert et al., 2017a). Fire activity in central Chile was mainly associated with above-average precipitation during winter of the previous year and with dry conditions during spring to summer. The later association was particularly strong in the southern, wetter part of the study region. Maximum temperature has a positive significant relationship with burned area across the study area, with stronger correlations towards the south. Fires in central Chile were significantly related with El Niño

Southern Oscillation (ENSO), through rainfall anomalies during the year previous to the fire season. The Antarctic Oscillation (AAO) during winter through summer was positively related with fires across the study area due to drier/warmer conditions associated with the positive polarity of this oscillation. Climate change projections for the region reveal an all-season decrease in precipitation and increases in temperature, that may likely result in an increment of the occurrence and the area affected by fires as it has been observed during a multi-year drought afflicting central Chile since 2010.

The mega drought and its impact on wildfires

Our findings indicate that during the 2010-2015 mega drought, the number of large-scale forest fires (>200 hectares) from Valparaı́so to La Araucanı́a Regions has increased in 27% and the total burnt area by 69% compared to the historical average in the fire records starting in 1985 (Gonzalez et al., 2017). Moreover, during the fire seasons through the mega drought, the area affected 106.000 and 126.000 hectares, respectively. This is the only time in the historical record in which there are two consecutive fire seasons with a burnt area >100.000 hectares in a particular year and contrasts with the mean annual area of 54.000 hectares burnt since 1985. This is the result of the occurrence of large fires during the mega drought, as a consequence of the inverse relationship between rainfall and positive correlation with temperature and the total burned area (Urrutia-Jalabert et al., 2017a). The increase in forest fires has been especially dramatic in the Metropolitan and El Maule Regions, and has affected forestry plantations mainly (20,000 hectares per year), which is equivalent to 34% of the total burnt area. Another impact of the mega drought is the constant lengthening of the forest fire season. Since 2010 the fire season has been extended all year around. For large fire events during the mega drought the average season length increased by 64 days (41%), comparing 1985 to 2009 with 2010 to 2015 (Gonzalez et al., 2017).

Climate reconstructions

The shortness of streamflow instrumental records (<50 years in most cases) severely limits the understanding of the availability and variability of water resources. This also reduces our capability of disentangling natural versus human-induced effects on water provision. In collaboration with researchers from other lines, and from elsewhere, we have tackled the challenges of developing multi century streamflow reconstructions from tree-rings, most of them starting in 1600 AD. We developed two new reconstructions (Bio Bio and Baker rivers), and we analyzed streamflow temporal and spatial variability as well as their climatic drivers along a latitudinal gradient ranging from 35º - 48º S (Lara et al., 2015; Munoz et al., 2016). This gradient includes Mediterranean-subtropical climatic regimes (Maule river) driven by ENSO to oceanic-wet temperate climates at higher latitudes (Bio Bio, Puelo and Baker rivers) having the Southern Annular Mode (SAM) as the main climatic driver. Puelo and Baker rivers streamflow show a steady decreasing trend in the last decades, that is unprecedented, and all rivers have an increase in the frequency of extreme high and/or low events in the twentieth century. This information is highly relevant for planning and decision making.

Other contributions

We have studied water and carbon balances to determine actual evapotranspiration and if the endangered long-lived *Fitzroya cupressoides* forests function as carbon sinks or sources (Urrutia-Jalabert et al., 2017b). For this purpose, we installed a closed-path Eddy covariance system in a 36-m height tower at Alerce Costero National Park in the Coastal Range of Southern Chile (40° 10' S- 73° 26' W). We are also monitoring of soil respiration and four long-term closed-chambers. Energy balance components have been estimated by complementing the sensors described with a net radiation sensor and three soil heat flux plates.

Real time monitoring of drought conditions and its future projection is key for the implementation of adaptation actions to climate variability and change. One method to tackle this is through the Palmer Drought Severity Index that is closely related to streamflow and soil moisture. The team contributed to its formulation, and applied to the Amazon basin (Blunden et al., 2016; Jiménez-Muñoz et al., 2016). In another study, it was proposed that tree growth in the Monarch Butterfly Biosphere Reserve is reduced in years of low winter-spring precipitation combined with high summer temperatures, a scenario which is likely to occur as a consequence of global climate change (Carlón Allende et al., 2016).

In collaboration with other CR2 members, an extensive data base with streamflow records of Chile including >700 watersheds spanning from 18º - 54º S has been prepared and will soon be made public in the CR2 site [Alvarez-Garretón et al a), in preparation]. In addition, we have documented the reduction of water provision as an ecosystem service in watersheds with higher relative area of forest plantations compared to total forested area (plantations + native forests) for 69 watersheds located between 35ºS and 41ºS for the period 1980-2016 [Alvarez-Garretón et al. b in preparation]. This is consistent with higher canopy interception and evapotranspiration rates associated with fast growing plantations compared with native forests. These negative relationships are consistent with lower water yield of plantations compared to native forests documented for Southern Chile (Lara et al., 2013; Lara et al., 2014a; Lara et al., 2014b; Little and Lara, 2014; Little et al., 2015) and as a dominant pattern in South America (Jones et al., 2017).

To study climatic variability and change in mountain ecosystems and the effect of *Araucaria araucana* forest canopy in snow accumulation and contribution to the watershed water balance, we have installed three meteorological stations and one fluviometric station in Reserva Nasampulli, Araucania region (39º 05´S 72º 42´ W at 1260 and 1450 m of elevation). This work is in collaboration with the Department of Civil Engineering, University of de Chile and the Center of Scientific Studies in Valdivia.

Human Dimensions

In the first phase of CR2, we assembled disciplines in law, sociology, anthropology, social psychology, and economics under Human Dimensions (HD). In a way, this highlighted a "new" area of expertise for the natural scientists that constitute the majority of CR2 researchers. Also, it allowed an internal disciplinary and interdisciplinary development for the HD team itself, which took a great effort. Now, once the relevance of their expertise is apparent to all, we can better integrate these fundamental sciences within the framework of facing complex issues.

Resilience in the face of climate variability and change

The concept of resilience refers to a system's capacity to resist and recover from the effects of perturbations in a timely and effective way. Even though this term is vastly used, its formal definition and its use differ considerably among authors and practitioners. Thus, a substantial effort was devoted to the conceptualization of resilience, and to build a common language among CR2 researchers. A systematic review of scientific literature showed how the term is being increasingly used in academia, however, it made also evident that the underlying conceptualizations differ diminishing its pragmatic utility and effectiveness (Adler et al., 2015). Also, the paradigms of "action-research" and "trans-disciplinary research" were used particularly when analyzing adaptation strategies to drought and disasters in communities (Aldunce et al., 2016a; Aldunce et al., 2016b; Aldunce et al., 2017b; Borquez et al., 2017). In this framework, researchers organized group sessions with the communities for the purpose of assessing and possibly to improve the effectiveness of their strategies (Aldunce et al., 2017b). Further work is looking at recent disasters in Chile like the March 2015 flood in Atacama and the fires in summer 2017 in central Chile. Interestingly, the CR2 conceptualization was adopted in the report of the presidential commission on natural disasters (CREDEN, 2016). Further work analyzed social-ecological resilience, in order to assess the capacity of the Chilean water model to face situations of water stress, considering the basic attributes of resilience: redundancy, diversity and flexibility; connectivity, collaboration and collective action; social-ecological memory and learning; self-organization and governance of system changes. This analysis, made for the Limarí basin (~30°S), evidences the lack of sufficient regulation and the overexploitation it permits. Also, it also stresses how cultural aspects also are important and some of them could be affecting other basins and weakening their resilience to water stresses, as for instance mistrust and de-valorization of local knowledge (Urquiza and Billi, 2017).

Governance of climate change

From a legal point of view, the climate change phenomenon challenges traditional concepts such as "causality", "damage" and "right" (Kugler and Moraga Sariego, 2016; Moraga Sariego and Mieckevi, 2017). Additionally, it is usually argued that a new kind of governance is needed to deal with this phenomenon that should include public participation as well as involvement from different levels of governments. As a first step to address these issues, we reviewed the bodies responsible for climate change (Moraga Sariego and Araya, 2015). Although increasingly and transversally present in ministries and offices, and in principle articulated via the Committee of Ministers for Sustainability (Energy, Public Works, Mining, Health, Agriculture, Construction, and Transportation) leaded by the Ministry for the Environment, its relative importance in the sectorial agendas varies, and lacks a coherent set of rules and budget. Moreover, public participation and consultation of scientists occur frequently but rules are set on a case by case basis. Secondly, we made an international comparative analysis of climate legislation (Moraga Sariego and Mieckevi, 2015). This shed light on pros and cons regarding the establishment of climate change act based on the experience of 13 countries out of 64 considered in the review, as well as on different possibilities regarding institutional arrangements. Thirdly, an *ex-ante* methodology for social and economic evaluation of climate legislation was developed (Arriagada, 2016). Based on these studies, and by means of a consultation process, organized by ourselves and a non-governmental organization (ADAPT Chile), among public and private stakeholders, including members of Parliament ("Climate bench"), we generated a proposal for a legal an institutional framework to address climate change in Chile (Moraga Sariego et al., 2016). As a result, we have stressed the need and the viability of enacting a law on climate change in Chile. This research was carried out under the auspices of the British Embassy in Chile and supported by the Ministry of Environment. As a follow up of the previous studies, in collaboration with the Ministry for the Environment and United Nations Environmental Program, and funded by the regional cooperation program between the European Union and Latin America (EUROCLIMA), we are working on the assessment of the legal and institutional framework for the adaptation of climate change at municipal and regional level in Chile. Our research included the decision-making processes at different levels of government, and we developed a proposal and a roadmap to improve the governance for adaptation to climate change at the territorial level in our country (Vasconi and Moraga Sariego, 2016).

Specific legal analyses on climate related legislation and practice were also carried out. One addressed the responsiveness of the State to face the mega drought and its consequences. In addition to the discoordination among the many bodies responsible, we could verify the inadequacy of the legislature. In fact, the mechanisms provided by the legislature in 1951, 1967 and 1981 remain in time, despite evolution in the understanding of the role of the State in the management of water resources, focused on a reparative rather than a preventive approach (Moraga Sariego, 2017b). A second study looked at how an Environmental Chilean Court has interpreted the citizen participation principle in the context of the environmental assessment processes in order to decide on claims against the Environmental Assessment Department. We show that this Court makes a broad interpretation of this principle, resulting in an effective application of it (Moraga Sariego, 2017a).

In addition to legal aspects of governance, a broader and more integrative approach, has been started under the umbrella of the Anthropocene. A historic review of environmental in Latin America was provided (Oryan and Ibarra, 2017). All this has allowed an interdisciplinary analysis of the evolution of climate governance in Chile [Arriagada et al, in preparation], and emphasized the need of an improved understanding of the science-policy interface to be systematically addressed in the second phase of CR2. Among other exchanges, the application *ex-ante* methodologies for social and economic evaluation will be central to contribute to the design of public policies.

Mapping and evaluating vulnerability in a changing climate

Vulnerability, like resilience, are broadly and loosely used concepts. In the framework of socio-ecological vulnerability, i.e., a system oriented vulnerability approach, a GIS-based mapping tool was developed and applied to evaluate the vulnerability to hydro-meteorological stresses in the Maule region in Chile [Nahuelhual et al, in preparation]. Maule is a region that has experienced extensive land use changes, and with a local farmer economy, being therefore particularly exposed to decreases in water resources. This work extended previous work evaluating ecosystem services (Nahuelhual et al., 2014; Nahuelhual et al., 2015; Nahuelhual et al., 2016). This mapping tool uses hydro-meteorological and socio-economic inputs, which are instrumental in quantifying the magnitude of the disturbance, the system's sensitivity to such exposures (in terms of changes in water flow rates and ecosystem services), and the system's capacity to resist and adapt.

In the context of the ongoing project on new regional climate simulations we are developing for the Ministry for the Environment, we are also looking at the various climate vulnerability assessments carried out so far for Chile. Although the Ministry has adopted the framework and definitions of the Intergovernmental Panel for Climate Change, the many studies differ in their conceptualizations. To this end, we are developing a protocol for vulnerability studies consistent with the conceptualization of resilience developed by the center [Urquiza et al, in preparation]. It is worth pointing out that the CR2 team has contributed to the analysis of vulnerability reported by Chile in its third national communication to the Climate Convention [Aldunce et al, in preparation].

Perceptions on climate change in Chile

The inclusion of a social psychologist allowed our collaboration with Ministry for the Environment in the application of the first national survey on the perception of climate change (Sapiains et al., 2017). The results show that 84% of Chileans believe climate change is definitely taking place, while 89% are of the opinion that human activity is entirely or partly responsible for the phenomenon. A majority of respondents have some understanding of climate change, and of its relation to changes in precipitation patterns, the regularity of the seasons, and overall temperatures.

Previously, the role of the media in the climate change debate in Chile was also object of analysis. The discourse in the digital written main written media was studied in order to know its impact in the public, as well as its importance as a source of information for decision makers and other relevant actors (Hasbún-Mancilla et al., 2017). The perception of climate change by civil society, private sector and government actors in order to know its impact in decision making and the development of public policy tools, with specific focus on the mega drought was also studied (Aldunce et al., 2017a).

Other contributions

A key issue today is that of climate justice. Currently, climate claims are increasing not only in Europe, Asia and North America, but also in South America. This kind of cases challenges courts to settle claims where the responsibility is shared by many actors and the damages have place not only within the jurisdiction of the national frontiers but also extraterritorially. Then judges must settle disputes where the traditional concept of "causality" is challenged by the scientific evidence, and the protection of legal interests need a new understanding in terms of extraterritorial responsibility. We addressed in particular, features of climate change damages, the legally-protected interest in climate change cases and the role of the judiciary power in climate litigation (Moraga Sariego, 2014; Kugler and Moraga Sariego, 2016).

The private and public actors related to drought were identified at both the national and local levels, and an actor map was created[7]. Also, their actions responses to climate change were gathered in a data base made available at CR2 web site[8].

As stated earlier, Human Dimensions played a key role in providing an organizational analysis for CR2 (Urquiza and Morales, 2017). Furthermore, they are also functional to a better definition of indicators for evaluating the center's performance in terms of outreach and impact [Ibarra et al, in preparation]. Also, the team is leading an academic network for the development of

[7] http://www.cr2.cl/recursos-y-publicaciones/identificacion-actores-sequia/
[8] http://www.cr2.cl/recursos-y-publicaciones/practicas-cambio-climatico/

knowledge about energy poverty. The objective is to build methodological instruments to evaluate fair access to clean energy considering the projections of climate change and natural disasters[9].

Modeling and Observing Systems

The team brings expertise on atmospheric chemistry, climate dynamics, climatology, economics, oceanography, applied mathematics, dendrochronology, computer science, emissions, and transportation engineering. This diversity is reflected in the many and transversal endeavors. Nevertheless, the team has been able to converge in various urbanization issues, and climate variability studies. Moreover, it has established the center's capabilities for climate modeling, and contributed to improving observational capabilities. Given its transversal character, the team has collaborated extensively with other research lines.

Climate variability and change derived from modeling

The analysis of simulations for the last millennium has allowed to evaluate the fluctuations in the South American Monsoon (Rojas et al., 2016), the Pacific anticyclone and the associated coastal upwelling zone [Rojas et al a, in preparation]. In both cases fluctuations are observed for the period also known as little ice age (circa 1700-1850), with a more intense Monsoon and a more contracted anticyclone. The review of a large number of flow simulations performed for the 21st century showed a robust drying in the south-central region of Chile, which translates into an even greater reduction in stream-flow [Bozkurt et al, in preparation]. Using the results of the projections of stream-flow together with past flow reconstructions and observations of the last decades, we are evaluating the impact of the projections on water rights for a basin in central Chile [Barría et al, in preparation]. This is a contribution to the Anthropocene integrative approach and it is developed jointly with economists and lawyers.

Based on the complete set of future climate simulations, the time at which the anthropogenic signal in rainfall emerges above natural variability was estimated and the impact on agriculture was evaluated [Rojas et al b, in preparation]. A study of the variability and projections of past multi-decadal precipitation in the region of northern Chile [Ortega et al, in preparation] from marine sediment-cores and future projections shows the maintenance of this type of variability in the area and an increase of extreme events. Additionally, simulations from the decadal predictability experiments (CMIP5) have been analyzed to explore the predictability of temperature and precipitation for northern, central and southern Chile up to decadal timescales [Albrecht et al., in preparation].

A climatology of waves and sea level

Using wave-height satellite data and a spectral wave model, it was found that the amplitude of the annual cycle of wave height is modulated by the presence of coastal atmospheric jets at low height (Aguirre et al., 2017). Offshore at the central coast of Chile, the wind increases during the summer, causing greater heights of waves generated locally. Due to this, the local waves present an annual cycle completely out of phase with respect to the remote waves, which increases in winter, suppressing the seasonal variability of wave height in this area. In addition to this, pessimistic climate projections suggest that spatial patterns of wind trends observed during the 21st century are consistent with spatial patterns of geostrophic wind trends, ratifying the importance of pole ward displacement of the subtropical anticyclones. However, the results also show a pole ward shift of intense wind events (coastal atmospheric jets at low altitude), whose occurrence would be mainly associated to the synoptic scale at mid-latitudes. Finally, the trends of upwelling favorable winds and sea surface temperature during the last decades off the coast of central Chile show a positive trend in upwelling favorable winds in much of the coast of Chile. In addition, the results show a negative trend of sea surface temperature. Future changes in sea level affecting Chile were analyzed for the 21st century for the representative concentration pathway RCP4.5 and RCP8.5 scenarios (Albrecht and Shaffer, 2016). The total mean sea-level rise along the coast lies between 34 cm and 52 cm for the RCP4.5 scenario and between 46 cm and 74 cm for the RCP8.5 scenario, depending on the location and the steric/dynamic component estimate considered. This component is the main contribution in each scenario.

[9] http://www.uchile.cl/multimedia/132797/red-de-pobreza-energetica-de-la-u-de-chile

Climatologies of tropospheric ozone in the remote atmosphere

As part of the sub-regional program for the southern cone of South America, three stations were installed in Chile under the auspices of GAW and the Chilean Weather Office by the mid-1990. Namely, an O_3 sounding device on Rapa Nui (27ºS, 109ºW, 51 m a.s.l.); a surface O_3 monitor, meteorological and radiation sensors at Cerro Tololo (30ºS, 70ºW, 2200 m a.s.l.); and a multiband radiometer at Valdivia (39.8ºS, 73ºW, 10 m a.s.l.). Unfortunately, the Valdivia station was destroyed in a fire in the mid-2000. Cerro Tololo and Rapa Nui have been kept in operation rather continuously since the mid 1990's, approaching today a 20-year record each. Moreover, Cerro Tololo has been expanded. Presently, methane, carbon dioxide, carbon monoxide, radiation and aerosol monitors are operating there. A data set with a complete statistical analysis of 260 O_3 soundings conducted on Rapa Nui over the period 1994-2014 is presented in (Gallardo et al., 2016a). Furthermore, a climatology for this unique site is provided. The analyses show the influence of both tropical and subtropical/mid-latitude air masses at Rapa Nui. The former occurs in summer and fall when convective conditions prevail, and the latter in late winter and spring when subsiding conditions are recurrent. The occurrence of stratospheric intrusions in late winter and spring in connection with deep troughs and the presence of the subtropical jet stream is also apparent in the data set. There is evidence of an upward trend in ozone near the surface, which suggests the impact of local pollution. In the case of Tololo, a spring maximum is also apparent and connected to stratosphere-troposphere exchange (Anet et al., 2017). This seasonal maximum has shifted to earlier in the year, which is consistent with the stratospheric origin, and potentially with a warming signal. Both stations provide unique data for the world, and privileged sites for observing our changing climate.

Evolution of in situ and down-wind impacts of air pollution

Several projects conducted during these 4.5 years have focused on the study of urban pollution. These studies are motivated in part by the question about the potential impact of air pollution on the Andean cryosphere (Molina et al., 2015). On the one hand, a measurement campaign was conducted to measure the transport of urban pollution to the top of the Andes. On a first stage, measurements were taken during a winter week in a valley near the city of Santiago. Observations revealed episodic intrusions of the city's pollution into the valley. On the other hand, the dispersion of black carbon, an urban pollutant of interest for its potential impact on the Andean glaciers, was simulated using carbon monoxide as a tracer [Orfanoz et al, in preparation]. The results suggest that the dispersion of the pollutants up to the mountain range occurs mainly to the northeast and east. Thus, the model suggests that the pollutants emitted in Santiago are capable of reaching Andean glaciers at 4800 [m] altitude to the northeast of the city and with potential deposition of these contaminants in this place. Furthermore, the simulations suggest that the mechanism responsible for this transport is the thermally driven mountain-valley circulation. To complement the previous study, an offline chemical transport model called CHIMERE has been implemented and used to simulate the dispersion of both particulate matter and gaseous pollutants in the Santiago Basin. Its performance has been assessed against measurements from the monitoring stations of the network of the Ministry of Environment for a winter period [Mazzeo et al., in preparation]. Furthermore, the model is being used to simulate and quantify the transport of pollutants up into the Andes by simulating explicitly black carbon and particulate matter [Ordóñez et al., in preparation]. In addition, shallow ice cores were taken in two glaciers in the central Andes to study the past evolution of anthropogenic pollution in these places. Preliminary results of these measurements indicate accumulation of anthropogenic pollution, consistently with the model simulations [Lambert et al, in preparation].

The evolution of pollution in Santiago was studied and the sectors that contributed to this contamination were identified. For this, 15 years of metal analyses of air filters from the air quality monitoring stations of Santiago were analyzed (Barraza et al., 2017). The results suggest that there are a total of six sources contributing to the atmospheric PM2.5 concentration: vehicles (37%), industries (19%), copper smelters (14%), wood burning (12%), coastal sources (10%) and urban dust (3%). During the analyzed period, vehicular, industrial emissions from copper foundries and coastal sources decreased by approximately 21, 39, 81, 59 and 59% respectively, while wood burning did not change and urban dust increased in 72. A technique similar to that used in the aforementioned study was applied to identify sources contributing to Organic Carbon (OC) and PM2.5 in Temuco during the winter of 2014. The results indicate that the main sources were wood burning (46%), coal burning (4.5%), diesel vehicles (3.7%), dust (2.3%) and vegetative detritus (0.7%). Inorganic secondary PM2.5 (sulfates, nitrates and ammonium) contributed 4.9% and unresolved organic aerosols (including secondary organic aerosols) contributed with 38.4%. These unresolved aerosols together with primary emissions of wood burning imply that wood burning contributes 84% to the atmospheric concentration of PM2.5 (Villalobos et al., 2017).

One study has started estimating the effect of atmospheric pollution on health. Also a database was built with historical records of daily mortality at the communal level for the period 1990-2014. Preliminary descriptive statistics of mortality indicate that the causes of death associated with cardiac, respiratory and lung cancers represent 42 % of the total causes. We aim at assessing the fraction of this total is attributable to atmospheric pollution as both population and air quality have changed in Santiago [Véliz et al, in preparation]. In another study, by combining smart card statistics from Santiago's public transportation system and air quality modeling outputs, exposure to air pollution along transportations paths can be evaluated for frequent users of the public transport system (Trewhela et al., 2017).

Emission estimates and projections

Mobile emissions have been estimated and projected for Chile for the period 1988-2050 [Osses et al, in preparation]. To this end emission models and economic and technological scenarios have been used. Based on this, the team contributed to the first national inventory of black carbon, recently launched by the Ministry for the Environment. Also, by coupling smart card statistics for Santiago's public transportation system, with bus technology data and emission factors, a system for on line emission estimates has been tested.

Also, in a workshop held in Santiago, Chile in March this 2017, an initiative lead by CR2 has been started to build harmonized and consistent emission inventories for five Latina America countries (Argentina, Brazil, Chile, Colombia and Peru). In this initiative participate researchers from these five countries plus international experts in the construction of national emission inventories. The aim of this initiative is to provide governments, stakeholders and scientists with qualified scientific emission information to support the development and further evaluation of policies to minimize (health and climate relevant) atmospheric pollutant emissions. In the short term, the objective is to focus on five countries in Latina America (Argentina, Brazil, Colombia, Chile and Peru) but the long-term objective is to expand this effort to all countries in Latin America. The effort also considers the use of global databases and satellite data to constrain and validate emission estimates. Also, ratios of species collected in air quality stations help in constraining emission estimates and their evolution [Gallardo et al, in preparation].

Other contributions

A land use model was applied on a continental scale to study the impact of mixing vegetation. The results suggest that mixing different types of vegetation on the same surface increases the resistance of the ecosystem to climatic extremes such as summer droughts (Van den Hoof and Lambert, 2016).

Dust flow measurements were compiled from different paleo climatic databases. This compilation was used to construct a gridded map of mineral dust deposition. This map could serve in biogeochemical climate models as input data to estimate the contribution of mineral dust in changes of CO_2 at glacial-interglacial scales. Additionally, dust fluxes were estimated from marine sediments from the South Pacific, allowing estimating variations in dust flows on glacial-interglacial scales.

Methodologies to examine the suitability of a monitoring network to characterize the state of the atmosphere have been developed and applied. Using information theory, information content as well as the specificity and representativeness of the air quality-monitoring network in Santiago was determined (Osses et al., 2013). We also used a variational framework, to determine the optimal distribution of air quality monitoring stations in Santiago for carbon monoxide (Henriquez et al., 2015a). An interesting application is now being finalized, in which the global network of aerosol optical depth is being characterized [Henriquez et al, in preparation].

Extensive work has been carried out in an effort to better simulate the circulation in and downwind of urban areas. Using monitoring data and data collected in measurement campaigns, the Weather Research and Forecasting Model (WRF) has been optimized for central Chile [Ordóñez et al, in preparation]. Also, a low cost system for estimating urban canopy has been developed [Bravo et al, in preparation]. The system uses open data provided by *OpenStreetMap* to map building geometry. The system has been applied to Santiago and Buenos Aires, and now it is being compared with detailed data available from the Internal Revenue Office in the case of Santiago. Also, preliminary tests of the canopy effects were carried out using the urban canopy models of WRF.

The Optics and Photonic Center at University of Concepción (CEFOP) developed a Hemispherical Scanning Imaging Differential Optical Absorption Spectrometer (HIS-DOAS), for which CR2 will generate an inversion software. This instrument will provide measurements for various gaseous pollutants such as O_3 and NO_2. Furthermore, vertical profiles of aerosol concentration could be retrieved from the inversion of measurements at different azimuthal angles and measurements of O_2 and O_4. In addition to the previous instruments, work has started on the development of low cost sensors to measure particulate matter. At first, a few prototypes were built based on the sharp dust sensor (GP2Y1010AU0F). Yet after preliminary tests of these instruments against reference observations, the dust sensor has been replaced by *Plantower* sensors. Currently a new set of prototypes are being built based on the latter sensors.

The model currently run for air quality forecasting on an operational basis was developed an evaluated by CR2 researchers in collaboration with the Ministry for the Environment and the University of Iowa (Saide et al., 2016).

A recent work provides an estimate of the time left act if the Paris agreement is to be enforced (de la Fuente et al., 2017). It uses an equal per capita fairness approach to a global carbon budget, linking personal levels with planetary levels. It is shown that a personal quota of 5.0 tons of CO_2 is a representative value for both past and future emissions; for this level of a constant per capita emissions and without considering any mitigation, the global accumulated emissions compatible with the “well below 2 °C” and 2 °C targets will be exhausted by 2030 and 2050, respectively.

2. Formation of human resources in the discipline (maximum of 5 pages)

In total, there are 37 under graduate exams, 47 masters and 7 doctoral theses completed at the moment of writing this report. Also, 25 post-doctoral fellows have worked at CR2 over the past 4.5 years, some of them funded by CR2 and other via FONDECYT. Moreover, ca. 16 graduated research assistants have collaborated with us. A significant fraction of our master students as well as research assistants are now following PhD programs abroad. Some of our post-doctoral fellows have gotten academic or research positions (4). The list of post-doctoral fellows is presented in Table 1. The list of graduated students is shown elsewhere in this report.

Students and research assistants

The number of PhD theses completed is small in comparison with the number of researchers. This may reflect the lack of such programs in Chile, or the lack of an aggressive enough search for doctoral students. In the second phase we intend to attempt the creation of an inter-institutional program in climate and resilience research, and to better focus our search for doctoral fellows. Also, we have to speed up the graduation process for master students.

Many of our students have developed their exams and theses not only in the context of the research driven by CR2 but integrated into it. They have been instrumental to the work completed so far. Also, they have been eager to carry out inter and transdisciplinary research of high policy relevance. Our students and younger colleagues have acted as Guinea pigs venturing across the tenuous footbridges that link different fields of knowledge, and they have also shared their enthusiasm and their unlimited capacity to dream. More than once, they’ve forced us to change our paradigms – scientific or otherwise– which is probably a good thing, in these times of the Anthropocene. We have provided opportunities for their training in the international arena, and promoted their participation in symposia and conferences. However, these efforts have generally responded to occasional opportunities, and not to a systematic planning in support of their formal training. This should receive more attention in the form of a person in charge in a second phase, permitting a more focused budgetary and management effort. In any case, our students in general seem to appreciate the opportunity of working in a multi and interdisciplinary environment. Similarly, younger graduated researchers do also appreciate the environment, and the chance to transcend their science.

Also many of our research assistants, particularly those who had completed a master's degree are now abroad following doctoral programs in prestigious universities in fields of relevance for Chile and the center. We look forward to their return perhaps as post-doctoral fellows or young researchers.

Post-doctoral fellows

We made open calls for post-doctoral positions, and promoted the search for other funding under the second year. We also got post-doctoral fellows that having competed independently for funds, decided to develop their research in the framework of CR2. Ten out 25 post-doctoral fellows have in fact grants from FONDECYT, which is an indicator of their competitiveness. This is also reflected in the number of papers published by them. Moreover, 2 of them got already academic positions, and one a research position in a public office. In general, only a few senior researchers in natural science accumulate the majority of sponsorships for post-doctoral fellows. Our selection procedures require further improvement in order to engage more competitive post-doctoral fellows, and to expand the spectrum of expertise. Those improvements refer to better defined research projects, clear expectations, etc. Also, we are considering the opening of a few 5 year research positions for younger promising researchers that may be more appealing for coming to Chile both for foreigners and the Chilean diaspora (This would be done sacrificing short-term research assistants, who can be paid with other funds). The one such position we had (Dr. Fabrice Lambert) was successful in terms of science output, and international collaboration. In fact he got a permanent position at the Catholic University. In general though, the current funding situation of Chilean universities makes it hard to find academic positions.

Table 1. Post doctoral fellows affiliated to CR2 between 2013 and present.

Name	Last Name	Status	Research Area	Affiliation	Current position	Sponsoring Researcher	Funding Source	Research Topic
Camila	Alvarez Garretón	Active	ECO	UACH	Post-doctoral fellow CR2	Antonio Lara	CR2 (2016), Fondecyt 3170428 (2017-2019)	Hydrologic vulnerability to climate change: estimation and interpretation.
Jonathan	Barichivich	Active	ECO	UACH	Post-doctoral fellow CR2	Antonio Lara	CR2	Modeling carbon sequestration and water supply as ecosystem services under climate and land-use change.
Francisco	Barraza	Active	MOS	PUC	Post-doctoral fellow CR2	Fabrice Lambert	Fondecyt 3160639	Origin of the aerosol deposited on Andes Glaciers
Lucy	Belmar	Active	BGQ	UCH	Post-doctoral fellow CR2	Laura Farias	CR2	Understanding the biogeochemistry of coastal zones and marine minimum oxygen zones, evaluating the modulation of carbon, nitrogen and sulfur cycles in coastal environments with and without anthropogenic intervention and their effect over ecological niches and finally over human
Juan Pablo	Boisier	Active	CD	UCH	Post-doctoral fellow CR2	Roberto Rondanelli	Fondecyt 3150492	Projected precipitation changes in the South-East Pacific and in Chile: Assessment of uncertainties and physical processes.
Deniz	Bozkurt	Active	MOS	UCH	Post-doctoral fellow CR2	Rene Garreaud	CR2 (2013-2014)/ Fondecyt 3150036 (2015-2016)	Regional climate processes and future hydroclimate of Central Chile.
Cecilia	Ibarra	Active	HD	UCH	Post-doctoral fellow CR2	Raúl O`Ryan	CR2	Enhancing innovation to manage climate change challenges: what can be learned from Chilean efforts to improve environmental performance?
Andrea	Mazzeo	Active	MOS	UCH	Post-doctoral fellow CR2	Nicolás Huneeus	Fondap CR2	Regional climate forcing by aerosols over and downwind Santiago, with emphasis on absorbing aerosols, using a combined modeling and observational approach
Camila	Tejo	Active	ECO	UACH	Post-doctoral fellow CR2	Mauro Gonzalez	Fondecyt 3160707	Ecological relevance of the canopy of the giant alerce (fitzroya cupressoides) and its consequences for management and conservation
Rocío	Urrutia-Jalabert	Active	ECO	UACH	Post-doctoral fellow CR2	Antonio Lara	Fondecyt 3160258	Vulnerability of Fitzroya cupressoides or Alerce to climate change (warmer and drier summers in southern Chile) using ecophysiological tools

Raúl	Valenzuela	Active	CD	UCH	Post-doctoral fellow CR2	René Garreaud	Fondecyt 3170155	Atmospheric rivers in the southeastern pacific and their impact on extreme orographic precipitation
Catalina	Aguirre	Inactive	MOS	UV	Academic Universidad de Valparaíso/ Adjoint research CR2	Maisa Rojas	Fondecyt 3150329	Viento costero de Chile central: la influencia de la surgencia y proyecciones futuras
Frauke	Albrecht	Inactive	MOS	UDEC	Post-doctoral fellow Institute for Oceanographic Research	Gary Shaffer/Nicolás Huneeus	CR2	Downscaling and application of global mean sea-level rise to the coast of Chile using spatially-resolved models of ocean circulation and warming, (land ice) self-gravitation and isostatic adjustment, until December 2014. Thereafter she works on the analysis of decadal projections.
Paola	Arias	Inactive	MOS	UCH	Academic and Head of environmental School Universidad de Antoquia (Colombia)	Maisa Rojas	Fondecyt 3140570	Variability of the South American monsoon circulation
Jie	Chang	Inactive	CD	UCH	Unknown	Patricio Moreno	ICM Paleoclima	Quantifying the Southern Hemisphere terrestrial temperature changes from the last millennium to the glacial times by using both traditional and novel palaeo-limnological techniques.
Carola	Flores	Inactive	BGQ	UDEC	Post-doctoral fellow CEAZA	Eugenia Gayó	CR2 (2016), Fondecyt 3170913 (2017-2019)	Human adaptation history and past local sea surface temperature along the southern coast of the Atacama Desert
Caitlin	Frame	Inactive	BGQ	UDEC	Unknown	Laura Farías	CR2	Production, destruction, and transport of the trace greenhouse gases nitrous oxide (N_2O) and methane (CH_4) in the environment.
Christian	Little	Inactive	ECO	UACH	Researcher of Forest Institute (INFOR-Chile)/ Adjoint Research CR2	Antonio Lara	CR2	Multi-scale relationships for quality and quantity of water services in forest watersheds
Kristina	Pistone	Inactive	MOS	UCH	Postdoctoral Fellow, NASA Postdoc Program, NASA Ames Research Center	Laura Gallardo	Fullbright	Aerosol climatology for Santiago
Cinthya	Ramallo	Inactive	CD	UCH	Independent Consultant	Rene Garreaud	CR2	Estudio de la caracterización hidrológica de años secos
Catherine	Van den Hoof	Inactive	CD	UCH	Post-doctoral fellow Global Change and Sustainability Research Institute,	Rene Garreaud	FONDAP/FONDECYT	Coupling between air temperature and precipitation changes

					University of the Witwatersrand. Johannesburg.			
Karina	Véliz	Inactive	MOS	UCH	Academic University Diego Portales, Adjoint research CR2	Laura Gallardo	CR2	Analyze literature on the effects of air pollution on health and compile data on air pollutants, hospital admissions and mortality.
Nancy	Yáñez	Inactive	HD	UCH	Independent Consultant	Pilar Moraga	CR2	Dogmatic analysis of water legislation in the framework of human rights
Mariela	Yévenes	Inactive	BGQ	UDEC	Unknown	Laura Farías	CR2 (2013-2014), Fondecyt 3150162 (2015-2017)	Reactive nitrogen sources and their cycling in river catchment areas subjected to a strong land use change and a water deficit drainage, the case of central-southern Chilean rivers.
Carlos	Zamorano	Inactive	ECO	UACH	Academic Universidad de Aysen / Adjoint research CR2	Antonio Lara	CR2	A spatial multi-criteria approach to identify active-passive forest restoration areas for biodiversity conservation, water provision, and carbon sequestration

3. National and international collaboration (maximum of 4 pages)

As stated earlier and illustrated below, CR2 exhibits a vast national and international network of collaboration. This network grew out of previous cooperation of individual researchers but more and more CR2 as such appears as the key-partner. These collaborations have produced co-authorship of papers and reports, shared researchers, and joint projects. Here we highlight a few of these, in particular those involving CR2 beyond individuals, first nationally and then internationally.

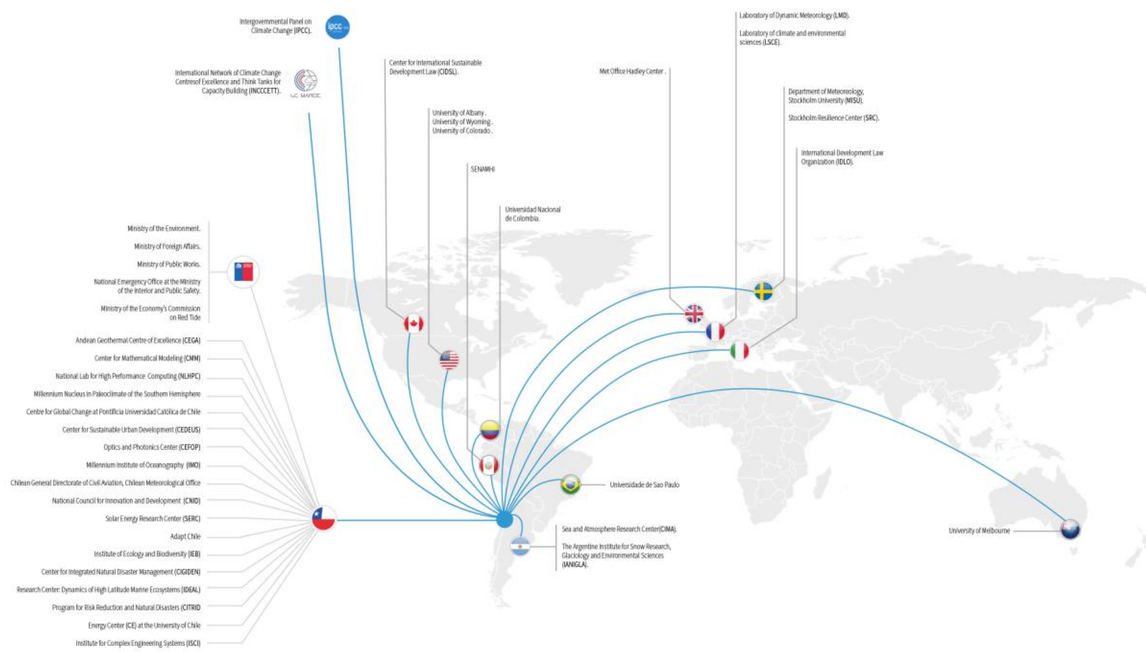

Figure 1. Illustration of national and international connections of CR2.

National Collaborations

Shared-researchers with centers of excellence

- We share Dr. Axel Osses with the **Center of Mathematical Modeling**. The collaboration refers to applications of inverse problems and data assimilation techniques. Also, occasionally we have collaborated with Dr. Juan Carlos Maureira who is an expert in high-performance computer. Also, we have made extensive and intensive use of the **National Laboratory for High Performance Computing** (NLHPC). Furthermore, we have contributed to the acquisition and development of a high-standard storing facility at NLHPC. Of course, we have supported their applications for funding, and promoted the existence of a centralized facility. We also count with the advice of Dr. Jaime San Martín who is a member of our National Advisory Panel.
- Dr. Pilar Moraga is a principal investigator of CR2 and an associate researcher of the **Center for Solar Research** (SERC). Also, Dr. Anahí Urquiza (adjoint researcher) has been partially linked to SERC. This has facilitated the collaboration around energy issues, energy poverty, and contributions to **the** *Mitigation Action Plans and Scenarios led by SERC and the Center of Energy, University of Chile*. Two outstanding products of this collaboration refer to: 1) CR2 and SERC contributions to the Chilean Strategy for Energy (Energy 2050); 2) the creation of a course for professionals (Continues Education) on **Climate Change and Low Carbon Development**. In

first turn, the course assembles 12 professionals working in the public and private sectors[10]. This course may eventually become a master program.

- Dr. Laura Nahuelhual, previously (2012-2016) associate researcher, and Dr. Gustavo Blanco, adjoint researcher, respectively, are now principal and associate researchers of the **Center for Dynamics of High Latitude Marine Ecosystems** (IDEAL), which started in 2016. On the one hand, the work initiated by Dr. Nahuelhual on vulnerability mapping is a topic of common interest for which in addition to expertise, we share a research assistant (Dana Jiménez). On the other hand, with both Dr. Blanco and Dr. Nahuelhual we collaborate on governance issues.
- Dr. Marcela Munizaga, an expert in transportation engineering, is the leader of the Smart City initiative within the **Institute for Complex Engineering Systems** (ISCI). She joined CR2 as an adjoint researcher in early 2016. This has allowed the development of graduate theses coupling emissions and pollutant exposure to large data bases of trip statistics in Santiago. The structural character of mobility for urban development offers an opportunity for efficient mitigation of emissions of both air pollutants and climate forcers. The city modeling capabilities already existent in ISCI, in combination with socio-economic data and atmospheric modeling outputs will allow us project emissions and exposure to various threats for the next decades.
- We share Dr. Ricardo De Pol-Holz with the **Millennium Institute for Oceanographic Research** (IMO). In this framework, collaboration on the carbon biogeochemistry in oceanic "extreme" zones (marine anoxic zones, deepest trenches) is developed. Also, it allows sharing of laboratory infrastructure as well as access to marine platforms and expeditions.

Joint projects

- Science communicators within the **Andean Geothermal Center of Excellence** (CEGA, Sofía Otero), the Institute of Ecology and Biodiversity (IEB, Dr. Nélida Pohl) and CR2 (first Luz Fariña, later Nicole Tondreau), in collaboration with researchers at CEGA (Linda Danielle) and CR2 (Laura Gallardo) developed *Julieta en Tierra de las Niñas*. This collaboration has been extended to other initiatives and outreach activities, including seminars, capacity building, etc.
- The chapter on climate vulnerability of the third national communication of Chile to the Climate Convention was a joint effort by CR2 and the **Center for Global Change** (CCG) at the Catholic University. Initially, CR2's contribution involved the participation of Dr. Paulina Aldunce (associate), Dr. Anahí Urquiza (adjoint), and Eng. Gloria Lillo (research assistant). Later on as the contents of this study are leading to associated peer-reviewed publications, other CR2 researchers have started participating including Dr. René Garreaud (principal investigator), Dr. Maisa Rojas (associate) and Dr. Laura Gallardo (principal investigator).

International Collaborations

- Since the latest Conference of the Parties for the Climate Convention held in Marrakech, CR2 belongs to an **international consortium of centers of excellence** intended to promote capacity building and to explore means to monitor the Paris Agreement over coming years (INCETT). In the context of the INCCCETT network, CR2 with the Basque Center for Climate Research (BC3) have begun drafting a concept note for a joint project on Strengthening Climate Resilient Governance in Latin American Cities. The Inter-American Institute for Global Change Research (IAI) would also be involved in this project. A first guiding question would be how to increase climate mitigation and resilience following a multilevel participatory approach that creates the information and commitment necessary to reduce climate vulnerability, territorial inequality and inefficient resource use? The proposal is to conduct pilot projects in two Latin American cities (Chile and Brazil) focusing on participation and provision of indicators.
- A **network on local adaptation to climate change, transdisciplinary and social learning** allowed in 2013-2014 (REDES 130066) the establishment of collaboration with distinguished scholars: Sandrine Maljean-Dubois, Mathilde Boutonnet (University of Aix Marseille), Markus Gehring and Marie-Claire Cordonnier (Cambridge), Víctor Galaz (Stockholm Resilience Centre), and Carolina Adler (Institute for Environmental Decisions, Switzerland). In this context, 4 master

[10] https://ecodie.cl/diploma-cambio-climatico-y-desarrollo-bajo-en-carbono-un-desafio-interdisciplinario/

theses were developed, and several publications informed elsewhere in this report, as well as seminars and symposia.

- An international **network on building harmonized and consistent and validated emission inventories** (REDES 150043) was recently launched at CR2 with five South American countries. The aim of this initiative, led by Dr. Nicolás Huneeus, is to provide governments, stakeholders and scientists with qualified scientific emission information to support the development and further evaluation of policies to minimize (health and climate relevant) atmospheric pollutant emissions. In the short term, the objective is to focus on the five countries but the long-term objective is to expand this effort to all countries in Latin America and the Caribbean. Data generated within EMISA will allow, among other things, to assess the potential environmental impacts and implications of different mitigation strategies and plans, evaluate the environmental costs and benefits of different policies and estimate the climatic impact of different anthropogenic activities. In this initiative, in addition to several CR2 researchers, participate Hugo D. van der Gon (The Netherlands), Claire Granier (USA/France), Laura Dawidowski, Darío Gómez, Paula Castesana (Argentina), Néstor Rojas (Colombia), Odón Sanchez (Peru), Marcelo Alonso, María de Fatima Andrade, and Rita Youe (Brazil). The network also counts with the sponsorship of the International Global Atmospheric Chemistry Project (IGAC). An initial task undertaken by the group is the compilation and revision of emission and air quality data from several cities, and from global data bases as well as satellite products. The goal is to grow to a permanent activity in the Americas. For that purpose, additional national and international funding opportunities are being sought. For instance, in collaboration with European partners, a project was recently submitted to the Marie Skłodowska-Curie Research and Innovation Staff Exchange. Also, an individual project on wood burning emissions was submitted to CONICYT by Dr. María Paz Domínguez.
- In our attempt to understand orographic precipitation and climate change, the Climate Dynamics group of CR2 has maintained FONDECYT-funded research projects with Dr. Aldo Montecinos at the **Geophysics Department, Universidad de Concepcion (DGEO-UdeC)** and FONDAP center **CRHIAM**. The first project (AFEX: 2012-2014) at the beginning of CR2 culminated with the visit of Dr. Justin Minder, **University of Albany, USA**. One year later (2015), CR2, DGEO-UdeC, UAlbany and other institutions in USA teamed in the project Chile-Coastal Precipitation (CCOPE) conducted in the Nahuelbuta Mountains (south of Concepcion). Dr. Jim Steemburg and PhD. Student Leah Campbell, from **University of Utah**, USA, joined this initiative in 2016 and a new field campaign was conducted in the Andes of the BioBio region. In 2017, CR2 (Garreaud) initiated a new joint project (2017-2019) with Aldo Montecinos and Andres Sepulveda, at **DGEO-UdeC**, as well as Dr. Marcelo Barreiro (**Universidad de la República, Uruguay**) on the changes in the ENSO-precipitation relationships over central Chile.

4. Outreach

Along with scientific research, outreach to the non-expert public is a fundamental part of CR2's mission and activities, with a view to raising awareness and understanding of the phenomenon of anthropic climate change and its different impacts in Chile.

In 2013, the Center's communication strategy had as its main objective the brand positioning in the media, while in 2014 the idea was to present its researchers as a source of information for the press. In 2015 and 2016, the focus was to propose themes from the Center to the media, such as the Mega-drought Report, the Julieta Project, the Proposal of a Climate Change Law and the Posar Buoy, together with a high percentage of response to various phenomena related to the effects climate change and public policies to address it.

Thanks to this strategy, there has been a noticeable increase in the number of instances in which CR2 has been described or mentioned in the Chilean and international press in relation to climate change contingency topics, besides other matters directly involving the Centre, as mentioned previously, and that become part of the press agenda.

If we compare the four most diffused themes of each year in the press from 2013 to the first 3 months of 2017, the cross-cutting topic is climate change. Meteorology also has an important place, because most of the times it's related to extreme hydro-meteorological events, like floods, heat waves, among others. Forest fires in central and southern Chile in early 2017 also marked a significant communication milestone.

Another important issue is the Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change. For the Chilean media, CR2 is a source of information during the development of this summit, in which the Center has an active participation. National press usually does not send correspondents to the event, so the CR2 journalist becomes a key link to the media during the Conference.

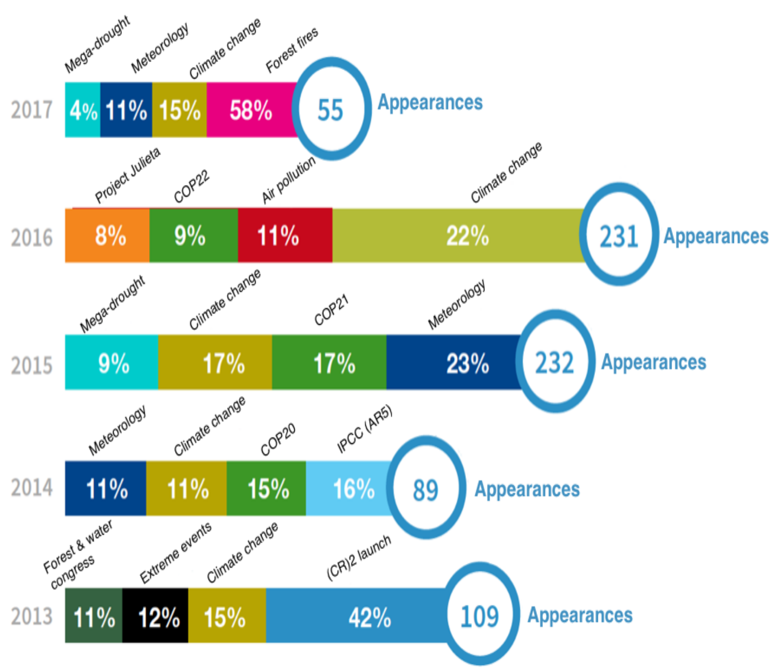

Figure 2. Illustration of media appearances along the years until March 2017. In addition to the number, it shows the themes treated.

Positioning communication themes from CR2: the case of mega drought

In addition to CR2's general communications strategy, certain issues require a special communication treatment because of their scientific relevance for the Center. This is the case of projects such as "Julieta in the Land of the Girls", the Posar Buoy, the Climate Explorer, the Proposal of a Climate Change Law and the Mega-drought Report.

To illustrate the different products associated with a relevant topic to the center, the case of the mega-drought report is explained. This is an interdisciplinary scientific work embodied in a dissemination document, edited and designed by the CR2's communications area, and released in November 2015. Also, associated products were made:

- Organization of a launch event at Universidad de Chile. It was attended by Ennio Vivaldi, President of Universidad de Chile, representatives of the Ministry of the Environment, the Ministry of Public Works, the Ministry of Foreign Affairs, water companies, among others.
- Animated video about the main results of the report, focused on the public of our social networks (teenagers, young adults).
- Artwork by the American artist based in Chile, Tully Satre, which represents three historic scenarios for the mega-drought in Chile.
- Press management in national and international media. The mega-drought was successfully positioned in the media and that can be seen until today: in 2015 it meant 9% of the total of CR2's press appearances, while in 2016 it represented 7%. During the first months of 2017, it reached 4% of total publications.
- An event of great relevance for CR2 was the presentation of the report to the President of the Republic, Michelle Bachelet. This generated more interest in the press and also in decision makers, which was reflected in the report that were made in the Senate, ministries, and other stakeholders.

Figure 3. Photographic reproduction of the art piece by Tully Satre depicting the expected evolution of the mega-drought in Chile. A copy of this picture was given to her Excellency President Michelle Bachelet at La Moneda in November 2015.

Another close communication with decision makers was generated through the implementation of the project "**Proposal of a legal and institutional framework to address climate change in Chile**" that settled the need of a law on climate change for Chile in the parliamentary agenda (creation of the "Climate bloc") and in the Ministry of Environment. A "climate week" was organized in collaboration with the British Embassy, and NGO ADAPT Chile, in which several high level national and international profiles participated including former president Ricardo Lagos, Sir David King, and the undersecretary for the Environment, Marcelo Mena. The project also included the realization of a video, and documents designed and edited by the Center's communications area. It is worth noticing that prior to the project addressing the climate law, there were no media mentions in this respect. Thus CR2 and it climate law project have added a new subject to the agenda.

Figure 4. Part of the "Climate Bench" and the CR2 team at the Faculty of Law, University of Chile.

Website and social networks

The website www.cr2.cl is the main informative channel of the Center. However, over the years we have seen that our social networks have become information channels of a greater or equivalent importance to that of the website. For example, between 2014 and 2015 there was a drop in web visits, but a very significant increase in the number of visitors to the Facebook and Twitter institutional accounts. This is consistent with the world trend in the use of social networks as information channels. Detailed numbers can be found in the annex "CR2's Communications Report".

On the other hand, the audiovisual production offered by our YouTube channel has increased over the years, offering original interviews to CR2 researchers and to other actors related to the Center's projects, as well as recordings of our seminars and talks. The institutional video, the mega-drought video and the climate change law video are also available, along with explanatory videos and television and radio appearances by CR2 researchers. Details of these numbers are available in the annex "CR2's Learning Metrics: Formative Indicators".

Science communication

RedLama

With a view to promoting direct contact with local communities, the students and research assistants at CR2 have created the Latin American Environmental Educational Network (RedLama), which seeks to communicate knowledge on climate change and environmental science.

Some of the projects implemented by RedLama are: inventory-taking of greenhouse gas emissions, carried out by schoolchildren in Biobío Region; building and maintaining a greenhouse at a school for handicapped children in Valdivia; and a series of presentations for primary and secondary school children in Valparaíso and Santiago.

Figure 5. Red Lama as in October 2016 and logo of the student's outreachnetwork

Explorers: from the Atom to the Cosmos

In mid-2016, CR2 began working with the Chilean video production company IMAGO in the realization of three in-depth stories about the Center's research. The chapters were presented on the TV channel 24 Horas of Televisión Nacional de Chile in January 2017. These stories addressed the effects of mega-drought in Chile, the impact of air pollution and climate change on the cities of the country, and the social dimension of climate change.

Figure 6. Still picture of the documentary on CR2 research produced for television in 2016.

Communicate your Science

Since 2015, CR2's communications team–jointly with CEGA and IEB (the Millennium Institute on Ecology and Biodiversity)–organize the annual participatory event "Communicate your Science" with the goal of training young scientists in the communication of science. The initiative is aimed at undergraduate and graduate students, and delivers basic tools for the communication of science, media relations, and for undertaking outreach programs.

Julieta in the Land of Girls

Also in collaboration with CEGA and IEB, the Centre developed the initiative "Julieta in the Land of Girls", an Explora Conicyt Popularization of Science and Technology project. This consists of a game showing a magnifying glass, a rain gauge, a notebook and other items, along with the Chilean animated character "Julieta". The purpose of the game is to trigger scientific curiosity in girls aged 7 to 11. "Julieta in the Land of Girls" received the 2016 Innovation in Scientific Education prize awarded jointly by *Fundación Ciencia Joven* and UNESCO to the best informal scientific education project, an acknowledgement of its contribution to narrowing the gender gap in Chilean science.

Figure 7. Field work of Julieta en la Tierra de las Niñas.

Diploma in Science Communication, Faculty of Sciences at Universidad de Chile

Since 2017, the communications area through one of its journalists is part of the teaching team of this diploma, the only of its kind in the country. With this participation, CR2 hopes to contribute to the training of professionals specialized in communication and dissemination of science in Chile.

The team on communications consists nowadays of two journalists (1.5 fulltime positions) and a part-time designer. Originally, it only considered one journalist. We had clearly underestimated the need for a communication's team in order to, on the one hand, address the many media consultations, and on the other hand, increase our capabilities as science communicators, and the overall efficiency of the process. We intend to have 2 fulltime journalists in the second phase, and to collaborate more closely with journalism schools in our universities, offering positions for trainees. Also, the development of short-science briefing is now being undertaken. We have also considered making the development of such recurrent briefings a duty of associate researchers.

Further details are presented in Annex referred to communications and outreach.

5. Contribution to public policies

Over the last 4.5 years, CR2 has been open and prone to collaborate with stakeholders, particularly in the public sector. Collaboration and exchanges have occurred in many instances, including specific projects, assessments, ministerial and presidential commissions, etc. We can account numerous instances of exchange as listed below. Some are reflected in the form of reports launched at La Moneda Palace by her Excellency President Bachelet, or in the discussion in Parliament of a climate act for Chile. Others are collaboration agreements signed by the parties, or contracted projects. Some other refer to presentations in Parliament made for senators and their consultants. Sometimes it can be "just" media appearances. In any case, we have found an increasing interest in the public sector and the private sector to establish such a connection with CR2.

So far, we have proceeded on an opportunity basis, applying a trial and error approach, with sometimes, a heavy toll on research hours. This is of course, not an optimal manner to approach the issue. Also, as wisely pointed out by our advisory panels, protocols and guiding principles selecting collaborations, particularly when private or political interests are stake must be developed. This is to be sorted out for our second phase.

To assess the success or impact of these many interactions is not straight-forward. In fact, in the second phase we want to address this interface in a systematic, scientific manner perhaps including scholars in the area of political science, and communication. Also, in addition to science, there is a need of establishing dedicated teams, perhaps "science brokers", and the figure of an acting manager who can play a role in bridging the gap.

A representative but not exhaustive list of collaborations with the public sector follows.

Table 2. Non-exhaustive list of collaborations between CR2 and the public sector

Public Entity	Theme	Actions/Contributions
Ministry for the Environment (MMA)	Climate simulations and vulnerability assessment	MMA has requested the collaboration of the CR2 in developing new regional climate simulations as well as methods for evaluating vulnerability to climate change. In this regard, both institutions signed an agreement in2016 for an 18 months project. The new projections will be accessible by way of an interactive platform that will support the design of public policy at a national level. CR2 is also leading a discussion group to assure the usability of the information.
	Mitigation Action Plans Scenarios (MAPS)	CR2 researchers contribute as experts to this initiative, in areas of legal expertise, emission scenarios, coordination of groups, etc.
	Climate Change National Action Plan (PANCC)	CR2 researchers got a project intended to structure and the contents of the Climate Change National Action Plan (PANCC), and also drafted the closing evaluation of the initiative. PANCC is the government's highest-level instrument for managing the response to climate change.
	Climate vulnerability for the third National Communication of Chile	CR2 jointly with the Center for Global Change at were contracted to write the chapter "*Chile's Vulnerability and Adaptation to Climate Change*" The document was prepared under the direction of the Ministry of the Environment, and describes the progress made by Chile in adapting to climate change from 2011 to 2016. This report was published and officially delivered to the United Nations in November 2016, during the Marrakech COP22 Summit.
Ministry of Foreign Affairs	Conferences of the Parties, Climate Convention and side events	The Directorate of the Environment and Oceanic Affairs at the Ministry of Foreign Affairs has been a key promoter of the participation of CR2 in COPs. CR2's participation in these conferences has become increasingly relevant. In 2016, CR2 worked closely with the Ministry of Foreign Affairs in promoting scientific cooperation in various areas of interested to the Ministry. In the context of this collaboration, both institutions jointly with the Inter-American Development Bank organized an official event at the Marrakech COP22 Summit. The event dealt with topics related to the financial implementation of the Nationally

		Determined Contributions (NDC) agreed at the Paris Climate Agreement.
Ministry of Public Works	Modeling and vulnerability assessments	In late 2016, the Center for Mathematical Modelling (CMM), the National Laboratory of High Performance Computing (NLHPC), the Ministry of Public Works (MOP) and CR2 signed an agreement aimed at establishing collaboration mechanisms in matters related to climate change and the modelling of this phenomenon, in order to contribute to the Ministry's policies and prospective studies IN 2015 this Ministry funded a study for analyzing the floods affecting the Atacama desert that year.
Chilean General Directorate of Civil Aviation, Chilean Meteorological Office (DMC)	Agreement for exchange of data and knowledge	In July2014, CR2 and DMC aimed at sharing relevant weather information and data analysis methods, and to develop climate services. The agreement also included training of DMC professionals, and the re-design of the climate bulletin of DMC. This agreement allows, among other thing, the real time exchange of weather data collected by DMC in Chile.
National Emergency Office (ONEMI) at the Ministry of the Interior and Public Safety		CR2 is a member of the scientific-technical committee, an advisory body of ONEMI. ONEMI aims to maximize its understanding of the various threats and develop effective means of managing risk in Chile. CR2 is also part of the national platform for the reduction of risk of disasters, which is a multi-sector initiative whose objective is to increase resilience to catastrophes in Chile.
National Council for Innovation and Development (CNID)	Assessment on research and innovation for disaster prevention and resilience, and water resources (Presidential Commission)	Members of CR2 participated in the central multi-sectorial commissions as, whose goal is to define guidelines in support of the country's strategic agenda on the matter. In late 2016, both commissions submitted their reports to the President of Chile, Michelle Bachelet, along with a series of recommendations and proposals to improve the management of water resources and preparations for natural disasters in the context of climate change in Chile. Now, in a second phase, the Commissions are mandated to define institutional approaches for establishing research consortia on these matters.
Ministry of Economy	Algae bloom commission	One CR2's PI was a member of the Panel of Independent Experts organized by the Ministry of the Economy, which analyzed the algae bloom phenomenon in Los Lagos and Aysén Regions in the summer of 2016. The team included five scientists convened by the Chilean Academy of Sciences. They worked to confirm or rule out a possible causative relationship between the dumping of decaying fish by fish-farm operators and the red-tide phenomenon. The final report of the Commission was delivered in November 2016.

IV. SUGGESTIONS FROM PREVIOUS EVALUATION

Describe how the suggestions provided by the evaluation panel and the FONDECYT Council in its previous evaluation report were taken into account by the Center.

The suggestions received from the FONDECYT Council, and particularly from the international review panel have been very much in line with those of our internal national and international panels, and certainly our own self-evaluation. But clearly, when posed by an independent party, the commandments and criticisms have a broader impact. Our overall perception is that we have addressed or at least advanced in translating the observations and suggestions into actions. Many of those, like making sure that our outputs reach society at large, are difficult to achieve as rather than actions they are actually processes involving many parties. The strengthening of the economic team is slowly beginning to translate into concrete outputs but no doubt this must be speeded up. Also, human dimensions as an area of expertise needs to be enhanced both in terms of theoretical developments, and in terms of pragmatic support. In addition to funding, this will require a more in depth search for academic partners in Chile and elsewhere.

Biogeochemistry's integration is occurring more and more. Unfortunately, the extensive and damaging algal blooms of last year put this area in the forefront, similarly to surges and other events. We expect that putting this research as an explicit integrative question will be helpful in facilitating the integration. Also the installation of the buoy, and the need for improved governance of the coastal areas, will enhance this development. Again, teaming up with other partners in Chile and elsewhere will be key.

We think that our new structure will be better suited for the development of mega drought like integrative questions, with concrete mid-term outputs, in addition to disciplinary and long-term quests addressing key issues such as the governance and policy-science interface. A theme like the Anthropocene, although in principle very theoretic and abstract, resulted nevertheless in policy relevant information and recommendations. During the second term of this year, we should produce one or more "reports to the nation" highlights these outputs.

V. OTHER RELEVANT ASPECTS: Analyze the effects that the creation of the Center produced on:

- ✓ Modifications in the originally proposed research activities, including changes in parameters like: quantity and quality of publications, development of new research areas, anticipated termination of initially proposed research goals, and achievement of variable degrees of successful multidisciplinary work in the different research lines, among others.
- ✓ The problems that could not be addressed,
- ✓ Main constraints to reach the proposed research goals,
- ✓ Other aspects considered relevant.

6. Evolution of objectives and organization

When starting the self-evaluation process, it became apparent that our eagerness in writing the initial proposal led to the statement of too many specific objectives/questions (19), which were at times posed as such, albeit very general or specific, sometimes like loose research themes. This made it difficult to assess the degree of progress. Nevertheless, for 18 out of 19, advances could be reported.

The teams of each research area were pretty uneven in terms of seniority, disciplinary training, and acquaintance among members. In the case of Human Dimensions and Modeling and Observing Systems there were expectations of a dual role as service providers and curiosity driven researchers that was difficult if not impossible to fulfil. Fortunately, the teams were plastic enough to adapt and the overarching objectives were met with significant degrees of progress.

In the first couple of years, the center's director played a dual role as head of CR2 –during the installation process—and as leader for Modeling and Observing System. In addition to the issue addressed earlier, her dual role resulted in a slower settlement of research foci for that team. In general, people in that line continued with their individual or associative projects but a bit discoordinated from one another. This situation improved greatly when Dr. Huneeus took over the leadership of the team. This impinged a direction to the research, and a substantial development took place.

The number of dedicated researchers in urbanization, and the underlying theme of coastal processes was small in relation to the objectives proposed. Over time, the urbanization team grew, whereas the oceanography area took advantage of extra CR2 collaborations. A learning from this is to better balance the allocation of resources and the ambition of objectives.

Regarding the integration of teams, we found difficulties related to actual geographical distances, and to disciplinary distances or different "ethos". Also, some groups had a tradition of working together (Ecosystem Services), and other were meeting each other for the first time (Human Dimensions). To address the former, we made an effort to meet in the different locations at least twice a year. To address the latter, common epistemological grounds had to be found.

As discussed in the section VI of this report, we have identified the need for re-structuring CR2, recognizing the actual diversity of disciplines cultivated in each, and by combining the original research lines under integrating complex issues.

7. Towards indicators for excellence and complexity

Indicators were far too simple to evaluate the diversity and complexity of a center of excellence. In fact, when writing the initial proposal, in the last minute we extrapolated a few ideas based on individual projects medium sized projects. Therefore, we sat a team that has reviewed the literature, and the experience of other centers to work towards more adequate indicators.

Over the years, CR2's community has become aware that many accomplishments and valuable work are not measured, monitored or reported, for example: maintaining and developing scientific databases, participating in public consultations on policy issues and being members of government commissions and roundtables. Activities like these take effort and resources and, we believe, are important to fulfill CR2's mission and strategic goals.

Under the premises that what is not monitored is not seen and, therefore, cannot be purposely managed, in July 2016 CR2 started a pilot project to generate metrics for formative assessment. The aim was to produce indicators to support strategic management and organizational learning, complementary to those requested by CONICYT. The project was presented to CR2's community during the November meeting in Malalcahuello and started with a pilot experience in the areas of scientific data development and communications, using an action research methodology. In the area of scientific data we produced indicators on the evolution of data products development and on usage of data services. For communications we focused on availability and access to on-line resources (publications and multimedia products). In the future formative indicators could be used for internal planning, goals' setting and self-monitoring. A preliminary report with results for the pilot project is shown in an Annex on indicators, it is being developed into a formal publication [Ibarra et al, in preparation].

8. Lack of wo/man power

Even though we can claim having doubled —from 22 to 49 individuals— or tripled —from 7.5 to 21 equivalent fulltime positions —the number of researchers with PhDs, the absolute figure remains small if compared with international hubs of research. More so if we acknowledge that the tripling in fulltime positions is largely made out of soft-money positions for post-doctoral fellows, with no clear path forward. This lack of actual dedicated wo/man power is a major barrier for Chilean research at large, and for climate and resilience research in particular. In fact, unless we can use CR2 money for permanent positions, which we cannot, we are not able to equalize the demand for knowledge in our areas of expertise. This is of course beyond the power of FONDAP or our universities. The only measure we can come up with is to increase the number of dedicated researchers by restricting the budget in some areas and creating, in the meantime, 5 year positions for early or mid-career scientists willing to come to this exciting country.

9. Maintenance and transference of knowledge

Setting up and maintaining observatories is difficult to sustain on the basis of 3 to 5 year grants. Exploiting the environmental wealth and diversity of Chile requires of long-term funding for logistics, facilities, and technicians. This is hardly affordable via our centers of excellence, and less so by our universities. This makes us somewhat worried regarding the fate of the systems we have developed or the instruments we have installed. Again, an issue that goes beyond the power of FONDAP but a limitation, nonetheless for our science.

VI. CENTER PROJECTIONS Analyze the Center projections after 4.5 years of funding

Our organizational study was made as a part of the process towards a CR2 second phase. In addition to management, protocols and sense of belonging, we devoted a great deal of time to discuss our future as a center of excellence. This discussion involved all CR2 members, from students to senior scientists but also support personnel. Our exchanges with our advisory panel, and recommendations from both the national and international review panels of CONICYT were also very useful to this end.

CR2 members appreciate as strategic definitions of CR2: Knowledge generation, Interdiscipline, and Science-society relationships. Moreover, CR2 members show a transversally high commitment and sense of belonging to CR2. Also, there is a general consensus on re-structuring CR2 around common topics or interdisciplinary problems to better enable interdisciplinary research and overcome the natural-social sciences dichotomy.

To identify the common topics, researchers were asked individually to propose integrative research themes/questions for the renewal process (~40 responses to a web questionnaire). These questions were classified and re-organized by principal investigators with the addition of Dr. Maisa Rojas, also a senior scientist. Some of the questions were re-formulations or new additions to the "old" themes of land use change, urbanization and water scarcity. Other were new themes and issues, i.e., coastal processes, Chile under 1.5 °C by 2030. Interestingly, all had a combination or aspects of curiosity driven science and problem solution science. Once classified, the questions were discussed and reformulated again in groups during a meeting held in Malalcahuello (Southern Chile) in November 2016. Thereafter, principal investigators defined small interdisciplinary teams –at least non-disciplinary– for writing proposal drafts for five themes: water, urbanization, land use, coastal processes, and "landing of Paris agreement". Working strategies of these teams varied from e-mail exchanges to dedicated meetings. The conclusions of these teams were presented in a meeting held last May in Patagonia. In this meeting a subset of post-doctoral fellows, and adjoint researchers plus almost all associate researchers participated. Part of our national advisory panel also participated. Using a discussion technique of successive approximations to more detailed formulations (similar to the discussion process of the ongoing IPCC process!), we identified five broad research areas around complex problems to be led by senior scientists (working titles):

- Water availability and (weather/climate) extremes
- Cities under climate variability and change
- Coastal processes and impacts
- Land use change
- Governance and policy-science interface

Concurrently with this, and as a manner to avoid silos, specific but transversal problems were identified and discussed. Analyzed examples were: fires, air pollution, hydro-meteorological extremes and their systemic impacts. These problems need the concurrence of all disciplines, and if defined as mid-range projects, they can deliver, along the way, outputs and answer of relevance for policy making. One can imagine early/mid-career scientists as leaders of these projects that, on the one hand, contribute to the overarching themes, and on the other hand, provide interfaces with decision making, and deliverables of societal relevance. To facilitate the latter, the need of counting with a transference team was recognized.

It is important to point out that we do not renegade from disciplinary science, curiosity driven science. On the contrary, it is the ground upon which we can build interdisciplinary and, perhaps, transdisciplinary adventures. But it is our general opinion that "the" center of excellence on climate and resilience research in Chile must necessarily embrace a multi-role approach. However, we are aware that this entails a careful allocation of resources, and systematic evaluations.

Obviously, ideas presented here require further refinement. However, the process experienced so far with CR2, and the eagerness and generosity shown by CR2 researchers, and the societal welcome to CR2, make us confident in finding ways to achieve more ambitious goals.

VII. FULFILLMENT OF THE INSTITUTIONAL COMMITMENT: Describe the support received by the hosting Institution such as physical space, funds, personnel (including hiring), scholarships, and contributions to the doctoral program.

Our responsible and associate universities have fulfilled their commitments regarding funds, facilities, personnel, etc.

The difficulties if any generally arise from conditions outside their control. For instance, hiring of personnel at the principal institution, i.e., University of Chile (public university), goes through lengthy and cumbersome procedures that oftentimes take too long. Additionally, contracts are issued for six month periods, and all too often the procedure takes several weeks and even months. In the case of post-doctoral fellows and research assistants, contracts are based on soft-money with no social security that must be acquired separately. Also, in the case of foreigners, immigration paperwork can take a lot of time, and again, sometime lengthy and cumbersome procedures. Moreover, only recently universities are starting to recognize the academic status of post-doctoral fellows.

At the Faculty for Physical and Mathematical Science, University of Chile there is a dedicated office for supporting the accounting of projects. This office is very helpful but it does not count with dedicated lawyers able to sort out the intricacies of inter-institutional agreements, or international acquisition of sophisticated equipment. This results in slow, and at times unspecific assessments, which hamper the agility of processes.

VIII. ADVISORY COMMITTEE: Indicate the way in which the committee contributed to the development of the Center. Discuss the most relevant problems found in carrying out this endeavor.

Our national and international committees have been immensely helpful and supportive. They have provided wise advice, guidance, and "tough" but constructive criticism when needed. The international panel is comprised of outstanding and generous scientists who enthusiastically have accompanied us along the way. It has been a privilege to have them and to share moments with them scientifically and otherwise.

The national advisory panel has been key in bringing to us the "real world" perspectives, and not seldom inspiring or challenging points of view. We are grateful for their contributions, and their friendliness.

We hope that in its second phase we still count with such a diverse, talented and generous panel.

Members of the International Advisory Panel

- Dr. David Battisti, Tamaki Chair and Professor of Atmospheric Sciences, University of Washington, USA.
- Dr. Guy Brasseur, Max Planck Institute for Meteorology, Germany
- Dr. Mark Howden, Theme Leader - Adaptive Primary Industries, Enterprises and Communities, CSIRO, Australia.
- Dr. Mary Scholes, Professor in the School of Animal, Plant and Environmental Sciences and Assistant Dean for Postgraduate Studies in the Faculty of Science, University of the Witwatersrand, South Africa.
- Dr. Tong Zhu, Chair Professor of Environmental Sciences, Cheung Kong Scholar Program at Peking University, China.

Dr. Carlos Nobre (Instituto Nacional de Pesquisas Espaciais, Centro de Ciência do Sistema Terrestre, Brazil), and Dr. Karen O'Brien (Professor at the Department of Sociology and Human Geography at the University of Oslo, Norway), could unfortunately not advise us because of other commitments and personal matters.

Members of the National Advisory Panel

- Jorge Carrasco, former Director of the Climatology Division at the Chilean Weather Office
- Francisco Donoso, Consultant and coordinator of the Sanitary Companies Association
- Rosa Escobar, private consultant with expertise in environmental studies for the mining industry.
- Maritza Jadrijevic, Officer at the Ministry for the Environment, Climate Change Division, Ministry for the Environment.
- Juan Ladrón de Guevara, Head for Chilean Agency for Climate Change and Sustainability, Ministry for Economy
- Karen Poniachick, Independent consultant and representative for Columbia University in Chile
- Jaime San Martín, Researcher and former Director for the Center for Mathematical Modeling

Dr. Raúl O'Ryan became a CR2 researcher in early 2016 bringing in his expertise in economics. Juan Ladrón de Guevara accepted to integrate the panel in early 2017.

IX. TABLES: Using the attached form, list all Center publications, congress and seminar presentations, courses, materials and other activities of dissemination during the first 4.5 -year period of the Center taking into account the following:

REPORT ONLY PUBLISHED MATERIAL INCLUDING THOSE WITH AN OFFICIAL DOI POINTER (e.g., with EARLY ONLINE ACCESS).

EXCEPT FOR BOOKS, ALL BACKUP DOCUMENTS MUST BE PRESENTED IN <u>DIGITAL FORMAT</u>. DO NOT SEND PRINTED COPIES.

ONLY PUBLICATIONS THAT ACKNOWLEDGE THE FONDAP PROGRAM WILL BE CONSIDERED.

10. ISI Publications

- ✓ For each publication, if applicable, the principal author and the corresponding author must be indicated using the following terminology:
  - [1] For principal author (example: Toro[1], J.)
  - [2] For the corresponding author (example: Toro[2], J.)
  - [3] For principal and corresponding author (example: Toro[3], J.)
- ✓ Include a digital copy of each <u>**PUBLISHED**</u> paper that has not been sent to CONICYT in past reports.

Aguilera-Betti, I., et al. (2017), The First Millennium-Age Araucaria Araucana in Patagonia, *Tree-Ring Research*, *73*(1), 53-56. doi: 10.3959/1536-1098-73.1.53.

Aguirre, C., R. D. Garreaud, and J. A. Rutllant (2014), Surface ocean response to synoptic-scale variability in wind stress and heat fluxes off south-central Chile, *Dynamics of Atmospheres and Oceans*, *65*, 64-85. doi: 10.1016/j.dynatmoce.2013.11.001.

Aguirre, C., J. Rutllant, and M. Falvey (2017), Wind waves climatology of the Southeast Pacific Ocean, *International Journal of Climatology*, *In press*. doi: 10.1002/joc.5084.

Ahmed, M., et al. (2013), Continental-scale temperature variability during the past two millennia, *Nature Geoscience*, *6*, 339-346. doi: 10.1038/NGEO1797.

Ahumada, G. A. (2016), Derecho internacional y política de adaptación al cambio climático en Reino Unido, *OPERA Colombia**(19), 11-34. doi: 10.18601/16578651.n19.03.

Albrecht, F., and G. Shaffer (2016), Regional Sea-Level Change along the Chilean Coast in the 21st century, *Journal of Coastal Research*, *32*(6), 1322-1332. doi: 10.2112/JCOASTRES-D-15-00192.1.

Alcamán, M. E., C. Fernandez, A. Delgado-Huertas, B. Bergman, and B. Díez (2015), The cyanobacterium Mastigocladus fulfills the nitrogen demand of a terrestrial hot spring microbial mat, *The ISME Journal*, *9*(10), 2290-2303. doi: 10.1038/ismej.2015.63.

Alcamán, M. E., J. Alcorta, B. Bergman, M. Vásquez, M. Polz, and B. Díez (2017), Physiological and gene expression responses to nitrogen regimes and temperatures in Mastigocladus sp. strain CHP1, a predominant thermotolerant cyanobacterium of hot springs, *Systematic and Applied Microbiology*, *40*(2), 102-113. doi: 10.1016/j.syapm.2016.11.007.

Aldunce, P., R. Beilin, J. Handmer, and M. Howden (2014), Framing disaster resilience: The implications of the diverse conceptualisations of “bouncing back”, *Disaster Prevention and Management*, *23*(3), 252-270. doi: 10.1108/DPM-07-2013-0130.

Aldunce, P., R. Beilin, M. Howden, and J. Handmer (2015), Resilience for disaster risk management in a changing climate: Practitioners’ frames and practices, *Global Environmental Change*, *30*, 1-11. doi: 10.1016/j.gloenvcha.2014.10.010.

Aldunce, P., R. Beilin, J. Handmer, and M. Howden (2016), Stakeholder participation in building resilience to disasters in a changing climate, *Environmental Hazards*, *15*(1), 58-73. doi: 10.1080/17477891.2015.1134427.

Aldunce, P., J. Handmer, R. Beilin, and M. Howden (2016), Is climate change framed as 'business as usual or as a challenging issue? The practitioners dilemma, *Environment and Planning C: Government and Policy*, *34*(5), 999-1019. doi: 10.1177/0263774X15614734.

Aldunce, P., R. Bórquez, C. Adler, G. Blanco, and R. Garreaud (2016), Unpacking Resilience for Adaptation: Incorporating Practitioners' Experiences through a Transdisciplinary Approach to the Case of Drought in Chile, *Sustainability*, *8*(9), art905. doi: 10.3390/su8090905.

Álvarez, C., T. T. Veblen, D. A. Christie, and Á. González-Reyes (2015), Relationships between climate variability and radial growth of Nothofagus pumilio near altitudinal treeline in the Andes of northern Patagonia, Chile, *Forest Ecology and Management*, *342*, 112-121. doi: 10.1016/j.foreco.2015.01.018.

Alvarez-Garreton, C., D. Ryu, A. W. Western, W. T. Crow, C.-H. Su, and D. R. Robertson (2016), Dual assimilation of satellite soil moisture to improve streamflow prediction in data-scarce catchments, *Water Resources Research*, *52*(7), 5357-5375. doi: 10.1002/2015WR018429.

Andrade-Flores, M., et al. (2016), Fostering a Collaborative Atmospheric Chemistry Research Community in the Latin America and Caribbean Region, *Bulletin of the American Meteorological Society*, *97*(10), 1929-1939. doi: 10.1175/BAMS-D-14-00267.1.

Anet, J. G., M. Steinbacher, L. Gallardo, P. A. Velásquez Álvarez, L. Emmenegger, and B. Buchmann (2017), Surface ozone in the Southern Hemisphere: 20 years of data from a site with a unique setting in El Tololo, Chile, *Atmos. Chem. Phys.*, *17*(10), 6477-6492. doi: 10.5194/acp-17-6477-2017.

Arias, P. A., R. Fu, C. Vera, and M. Rojas (2015), A correlated shortening of the North and South American monsoon seasons in the past few decades, *Climate Dynamics*, *45*(11-12), 3183-3203. doi: 10.1007/s00382-015-2533-1.

Barrett, B. S., D. A. Campos, J. V. Veloso, and R. Rondanelli (2016), Extreme temperature and precipitation events in March 2015 in central and northern Chile, *Journal of Geophysical Research: Atmospheres*, *121*(9), 4563-4580. doi: 10.1002/2016JD024835.

Berman, A. L., G. E. Silvestri, M. Rojas, and M. S. Tonello (2017), Accelerated greenhouse gases versus slow insolation forcing induced climate changes in southern South America since the Mid-Holocene, *Climate Dynamics*, *48*(1-2), 387-404. doi: 10.1007/s00382-016-3081-z.

Blanco, J. F., I. Correa G, C. Flores, and G. Pimentel G (2017), La Extracción Prehispánica de recursos minerales en el internodo Quillagua-Costa, desierto de Atacama, *Estudios atacameños*, *in press*, 1-26. doi: 10.4067/S0718-10432017005000003.

Boisier, J. P., P. Ciais, A. Ducharne, and M. Guimberteau (2015), Projected strengthening of Amazonian dry season by constrained climate model simulations, *Nature Climate Change*, *5*(7), 656-660. doi: 10.1038/nclimate2658.

Boisier, J. P., R. Rondanelli, R. D. Garreaud, and F. Muñoz (2016), Anthropogenic and natural contributions to the Southeast Pacific precipitation decline and recent mega-drought in central Chile, *Geophysical Research Letters*, *43*(1), 413-421. doi: 10.1002/2015GL067265.

Borquez, R., P. Aldunce, and C. Adler (2017), Resilience to climate change: from theory to practice through co-production of knowledge in Chile, *Sustainability Science*, *12*(1), 163-176. doi: 10.1007/s11625-016-0400-6.

Bozkurt, D., O. L. Sen, and S. Hagemann (2015), Projected river discharge in the Euphrates–Tigris Basin from a hydrological discharge model forced with RCM and GCM outputs, *Climate Research*, *62*(2), 131-147. doi: 10.3354/cr01268.

Bozkurt, D., R. Rondanelli, R. Garreaud, and A. Arriagada (2016), Impact of warmer eastern tropical Pacific SST on the March 2015 Atacama floods, *Monthly Weather Review*, *144*(11), 4441-4460. doi: 10.1175/MWR-D-16-0041.1.

Brasseur, G. P., and L. Gallardo (2016), Climate Services: Lessons Learned and Future Prospects, *Earth's Future*, *4*(3), 79-89. doi: 10.1002/2015EF000338.

Bravo, C., M. Rojas, B. Anderson, A. N. Mackintosh, E. Sagredo, and P. I. Moreno (2015), Modelled glacier equilibrium line altitudes during the mid-Holocene in the southern mid-latitudes, *Climate of the Past*, *11*(11), 1575-1586. doi: 10.5194/cp-11-1575-2015.

Cabezas, J., M. Galleguillos, and J. F. Perez-Quezada (2016), Predicting Vascular Plant Richness in a Heterogeneous Wetland Using Spectral and Textural Features and a Random Forest Algorithm, *IEEE Geoscience and Remote Sensing Letters*, *13*(5), 646-650. doi: 10.1109/LGRS.2016.2532743.

Cabezas, J., M. Galleguillos, A. Valdés, J. P. Fuentes, C. Pérez, and J. F. Perez-Quezada (2015), Evaluation of impacts of management in an anthropogenic peatland using field and remote sensing data, *Ecosphere*, *6*(12), art282. doi: 10.1890/ES15-00232.1.

Carlón Allende, T., M. E. Mendoza, D. R. Pérez-Salicrup, J. Villanueva-Díaz, and A. Lara (2016), Climatic responses of Pinus pseudostrobus and Abies religiosa in the Monarch Butterfly Biosphere Reserve, Central Mexico, *Dendrochronologia*, *38*, 103-116. doi: 10.1016/j.dendro.2016.04.002.

Castro-González, M., and L. Farías (2015), The influence of anoxia and substrate availability on N2O cycling by denitrification in the upper boundary of the oxygen minimum zone off northern Chile, *Journal of Marine Research*, *73*(6), 185-205. doi: 10.1357/002224015817391285.

Castro-González, M., O. Ulloa, and L. Farías (2015), Structure of denitrifying communities reducing N2O at suboxic waters off northern Chile and Perú, *Revista de Biologia Marina y Oceanografia*, *50*(1), 95-110. doi: 10.4067/S0718-19572015000100008.

Christie, D. A. (2016), Balance de masa glaciar, *Revista de geografía Norte Grande*(65), 239-241. doi: 10.4067/S0718-34022016000300013.

Cordero, R. R., et al. (2016), The Solar Spectrum in the Atacama Desert, *Scientific Reports*, *6*, art22457. doi: 10.1038/srep22457.

Cordova, A. M., J. Arévalo, J. C. Marín, D. Baumgardner, G. B. R. Graciela B. Raga, D. Pozo, C. A. Ochoa, and R. Rondanelli (2016), On the Transport of Urban Pollution in an Andean Mountain Valley, *Aerosol and Air Quality Research*, *16*(3), 593-605. doi: 10.4209/aaqr.2015.05.0371.

Cornejo, M., A. A. Murillo, and L. Farías (2015), An unaccounted for N2O sink in the surface water of the eastern subtropical South Pacific: Physical versus biological mechanisms, *Progress in Oceanography*, *137*, 12-23. doi: 10.1016/j.pocean.2014.12.016.

Cornejo D'Ottone, M., L. Bravo, M. Ramos, O. Pizarro, J. Karstensen, M. Gallegos, M. Correa-Ramirez, N. Silva, L. Farias, and L. Karp-Boss (2016), Biogeochemical characteristics of a long-lived anticyclonic eddy in the eastern South Pacific Ocean, *Biogeosciences*, *13*(10), 2971-2979. doi: 10.5194/bg-13-2971-2016.

Cuyckens, G. A. E., D. A. Christie, A. I. Domic, L. R. Malizia, and D. Renison (2016), Climate change and the distribution and conservation of the world's highest elevation woodlands in the South American Altiplano, *Global and Planetary Change*, *137*, 79-87. doi: 10.1016/j.gloplacha.2015.12.010.

Daniel, I., M. DeGrandpre, and L. Farías (2013), Greenhouse gas emissions from the Tubul-Raqui estuary (central Chile 36°S), *Estuarine, Coastal and Shelf Science*, *134*, 31-44. doi: 10.1016/j.ecss.2013.09.019.

de la Fuente, A., M. Rojas, and C. Mac-Lean (2017), Human-scale perspective of global warming: personal quota and zero emission year, *PloS one*, *in press*, 1-29.

Delgado-Baquerizo, M., et al. (2016), Human impacts and aridity differentially alter soil N availability in drylands worldwide, *Global Ecology and Biogeography*, *25*(1), 36-45. doi: 10.1111/geb.12382.

Delgado-Baquerizo, M., et al. (2013), Decoupling of soil nutrient cycles as a function of aridity in global drylands, *Nature*, *502*(7473), 672-676. doi: 10.1038/nature12670.

Díaz-Hormazábal, I., and M. E. González (2016), Spatio-temporal analyses of wildfires in the region of Maule, Chile, *Bosque*, *37*(1), 147-158. doi: 10.4067/S0717-92002016000100014.

Díez, B., J. A. A. Nylander, K. Ininbergs, C. L. Dupont, A. E. Allen, S. Yooseph, D. B. Rusch, and B. Bergman (2016), Metagenomic Analysis of the Indian Ocean Picocyanobacterial Community: Structure, Potential Function and Evolution, *PloS one*, *11*(5), art0155757. doi: 10.1371/journal.pone.0155757.

Eby, M., et al. (2013), Historical and idealized climate model experiments: an intercomparison of Earth system models of intermediate complexity, *Climate of the Past*, *9*(3), 1111-1140. doi: 10.5194/cp-9-1111-2013.

Escribano, J., L. Gallardo, R. Rondanelli, and Y.-S. Choi (2014), Satellite Retrievals of Aerosol Optical Depth over a Subtropical Urban Area: The Role of Stratification and Surface Reflectance, *Aerosol and Air Quality Research*, *14*(3), 596-607. doi: 10.4209/aaqr.2013.03.0082.

Escribano, J., O. Boucher, F. Chevallier, and N. Huneeus (2016), Subregional inversion of North African dust sources, *Journal of Geophysical Research: Atmospheres*, *121*(14), 8549-8566. doi: 10.1002/2016JD025020.

Escribano, J., O. Boucher, F. Chevallier, and N. Huneeus (2017), Impact of the choice of the satellite aerosol optical depth product in a sub-regional dust emission inversion, *Atmospheric Chemistry and Physics*, 1-22.

Farias, L., K. Sanzana, S. Sanhueza-Guevara, and M. A. Yevenes (2017), Dissolved methane distribution in the Reloncavi fjord and adjacent marine system during austral winter (41º-43ºS), *Estuaries and Coasts*, *in press*, 1-15. doi: 10.1007/s12237-017-0241-2.

Farías, L., V. Besoain, and S. García-Loyola (2015), Presence of nitrous oxide hotspots in the coastal upwelling area off central Chile: an analysis of temporal variability based on ten years of a biogeochemical time series, *Environmental Research Letters*, *10*(4), art044017. doi: 10.1088/1748-9326/10/4/044017.

Farías, L., L. Florez-Leiva, V. Besoain, G. Sarthou, and C. Fernández (2015), Dissolved greenhouse gases (nitrous oxide and methane) associated with the naturally iron-fertilized Kerguelen region (KEOPS 2 cruise) in the Southern Ocean, *Biogeosciences*, *12*(6), 1925-1940. doi: 10.5194/bg-12-1925-2015.

Farías, L., J. Faúndez, C. Fernández, M. Cornejo, S. Sanhueza, and C. Carrasco (2013), Biological N2O fixation in the Eastern South Pacific Ocean and marine cyanobacterial cultures, *PloS one*, *8*(5), art63956. doi: 10.1371/journal.pone.0063956.

Fernandez, C., M. L. González, C. Muñoz, V. Molina, and L. Farías (2015), Temporal and spatial variability of biological nitrogen fixation off the upwelling system of central Chile (35-38.5°S), *Journal of Geophysical Research: Oceans*, *120*(5), 3330-3349. doi: 10.1002/2014JC010410.

Fink, H. G., C. Wienberg, R. De Pol-Holz, and D. Hebbeln (2015), Spatio-temporal distribution patterns of Mediterranean cold-water corals (Lophelia pertusa and Madrepora oculata) during the past 14,000 years, *Deep Sea Research Part I: Oceanographic Research Papers*, *103*, 37-48. doi: 10.1016/j.dsr.2015.05.006.

Flores, F., R. Garreaud, and R. C. Muñoz (2013), CFD simulations of turbulent buoyant atmospheric flows over complex geometry: Solver development in OpenFOAM, *Computers & Fluids*, *82*, 1-13. doi: 10.1016/j.compfluid.2013.04.029.

Flores, F., R. D. Garreaud, and R. C. Muñoz (2014), OpenFOAM applied to the CFD simulation of turbulent buoyant atmospheric flows and pollutant dispersion inside large open pit mines under intense insolation, *Computers & Fluids*, *90*, 72-87. doi: 10.1016/j.compfluid.2013.11.012.

Florez-Leiva, L., E. Damm, and L. Farías (2013), Methane production induced by dimethylsulfide in surface water of an upwelling ecosystem, *Progress in Oceanography*, *112-113*, 38-48. doi: 10.1016/j.pocean.2013.03.005.

Galán, A., J. Faúndez, B. Thamdrup, J. F. Santibáñez, and L. Farías (2014), Temporal dynamics of nitrogen loss in the coastal upwelling ecosystem off central Chile: Evidence of autotrophic denitrification through sulfide oxidation, *Limnology and Oceanography*, *59*(6), 1865-1878. doi: 10.4319/lo.2014.59.6.1865.

Galbraith, E. D., et al. (2013), The acceleration of oceanic denitrification during deglacial warming, *Nature Geoscience*, *6*(7), 579-584. doi: 10.1038/ngeo1832.

Gallardo, L., A. Henríquez, A. M. Thompson, R. Rondanelli, J. Carrasco, A. Orfanoz-Cheuquelaf, and P. Velásquez (2016), The first twenty years (1994–2014) of ozone soundings from Rapa Nui (27°S, 109°W, 51 m a.s.l.), *Tellus B: Chemical and Physical Meteorology*, *68*(1), art29484. doi: 10.3402/tellusb.v68.29484.

Galleguillos, M., F. Jacob, L. Prévot, C. Faúndez, and A. Bsaibes (2017), Estimation of actual evapotranspiration over a rainfed vineyard using a 1-D water transfer model: A case study within a Mediterranean watershed, *Agricultural Water Management*, *184*, 67-76. doi: 10.1016/j.agwat.2017.01.006.

García-Plazaola, J. I., R. Rojas, D. A. Christie, and R. E. Coopman (2015), Photosynthetic responses of trees in high-elevation forests: Comparing evergreen species along an elevation gradient in the Central Andes, *AoB plants*, *7*, plv058. doi: 10.1093/aobpla/plv058.

Garreaud, R. D. (2013), Warm Winter Storms in Central Chile, *Journal of Hydrometeorology*, *14*(5), 1515-1534. doi: 10.1175/JHM-D-12-0135.1.

Garreaud, R., M. Falvey, and A. Montecinos (2016), Orographic Precipitation in Coastal Southern Chile: Mean Distribution, Temporal Variability, and Linear Contribution, *Journal of Hydrometeorology*, *17*(4), 1185-1202. doi: 10.1175/JHM-D-15-0170.1.

Garreaud, R., P. Lopez, M. Minvielle, and M. Rojas (2013), Large-Scale Control on the Patagonian Climate, *Journal of Climate*, *26*(1), 215-230. doi: 10.1175/JCLI-D-12-00001.1.

Garreaud, R. D., M. Gabriela Nicora, R. E. Bürgesser, and E. E. Ávila (2014), Lightning in Western Patagonia, *Journal of Geophysical Research: Atmospheres*, *119*(8), 4471-4485. doi: 10.1002/2013JD021160.

Gayo, E. M., C. Latorre, and C. M. Santoro (2015), Timing of occupation and regional settlement patterns revealed by time-series analyses of an archaeological radiocarbon database for the South-Central Andes (16°–25°S), *Quaternary International*, *356*, 4-14. doi: 10.1016/j.quaint.2014.09.076.

Gómez-González, S., F. Ojeda, P. Torres-Morales, and J. E. Palma (2016), Seed Pubescence and Shape Modulate Adaptive Responses to Fire Cues, *PloS one*, *11*(7), art0159655. doi: 10.1371/journal.pone.0159655.

González, M. E., and A. Lara (2015), Large fires in the Andean Araucaria forests: when a natural ecological process becomes a threat, *Oryx*, *49*(3), 394-394. doi: 10.1017/S0030605315000599.

González, M. E., P. J. Donoso, and P. Szejner (2015), Tree-fall gaps and patterns of tree recruitment and growth in Andean old-growth forests in south-central Chile, *Bosque*, *36*(3), 383-394. doi: 10.4067/S0717-92002015000300006.

González, M. E., P. Szejner, P. J. Donoso, and C. Salas (2015), Fire, logging and establishment patterns of second-growth forests in south-central Chile: implications for their management and restoration, *Ciencia e investigación agraria*, *42*(3), 11-11. doi: 10.4067/S0718-16202015000300011.

González–Reyes, Á., J. McPhee, D. A. Christie, C. Le Quesne, P. Szejner, M. H. Masiokas, R. Villalba, A. A. Muñoz, and S. Crespo (2017), Spatio-temporal variations in hydroclimate across the Mediterranean Andes (30°-37°S) since the early 20th century, *Journal of Hydrometeorology*, 1-44. doi: 10.1175/JHM-D-16-0004.1.

Guimberteau, M., et al. (2017), Impacts of future deforestation and climate change on the hydrology of the Amazon Basin: a multi-model analysis with a new set of land-cover change scenarios, *Hydrology and Earth System Sciences*, *21*(3), 1455-1475. doi: 10.5194/hess-21-1455-2017.

Hasbún-Mancilla, J. O., P. P. Aldunce-Ide, G. Blanco-Wells, and R. Browne-Sartori (2017), Encuadres del cambio climático en Chile: Análisis de discurso en prensa digital, *Convergencia*, *24*(74), 161-186.

Henriquez, A., A. Osses, L. Gallardo, and M. Diaz Resquin (2015), Analysis and optimal design of air quality monitoring networks using a variational approach, *Tellus B: Chemical and Physical Meteorology*, *67*(1), art25385. doi: 10.3402/tellusb.v67.25385.

Henríquez, W. I., P. I. Moreno, B. V. Alloway, and G. Villarosa (2015), Vegetation and climate change, fire-regime shifts and volcanic disturbance in Chiloé Continental (43°S) during the last 10,000 years, *Quaternary Science Reviews*, *123*, 158-167. doi: 10.1016/j.quascirev.2015.06.017.

Huneeus, N., et al. (2016), Forecasting the northern African dust outbreak towards Europe in April 2011: a model intercomparison, *Atmospheric Chemistry and Physics*, *16*(8), 4967-4986. doi: 10.5194/acp-16-4967-2016.

Huneeus, N., et al. (2014), Forcings and feedbacks in the GeoMIP ensemble for a reduction in solar irradiance and increase in CO_2, *Journal of Geophysical Research: Atmospheres*, *119*(9), 5226-5239. doi: 10.1002/2013JD021110.

Iverson, L., C. Echeverría, L. Nahuelhual, and S. Luque (2014), Ecosystem services in changing landscapes: An introduction, *Landscape Ecology*, *29*(2), 181-186. doi: 10.1007/s10980-014-9993-2.

J Alaniz, A., M. Galleguillos, and J. F. Perez-Quezada (2016), Assessment of quality of input data used to classify ecosystems according to the IUCN Red List methodology: The case of the central Chile hotspot, *Biological Conservation*, *204*, 378-385. doi: 10.1016/j.biocon.2016.10.038.

Jacques-Coper, M., and R. D. Garreaud (2015), Characterization of the 1970s climate shift in South America, *International Journal of Climatology*, *35*(8), 2164-2179. doi: 10.1002/joc.4120.

Jara, I. A., and P. I. Moreno (2014), Climatic and disturbance influences on the temperate rainforests of northwestern Patagonia (40 °S) since ∼14,500 cal yr BP, *Quaternary Science Reviews*, *90*, 217-228. doi: 10.1016/j.quascirev.2014.01.024.

Jiménez-Muñoz, J. C., C. Mattar, J. Barichivich, A. Santamaría-Artigas, K. Takahashi, Y. Malhi, J. A. Sobrino, and G. v. d. Schrier (2016), Record-breaking warming and extreme drought in the Amazon rainforest during the course of El Niño 2015–2016, *Scientific Reports*, *6*, art33130. doi: 10.1038/srep33130.

Joly, D., C. M. Santoro, E. M. Gayo, P. C. Ugalde, R. J. March, R. Carmona, D. Marguerie, and C. Latorre (2017), Late Pleistocene Fuel Management and Human Colonization of the Atacama Desert, Northern Chile, *Latin American Antiquity*, *28*(1), 144-160. doi: 10.1017/laq.2016.8.

Jones, J., et al. (2017), Forests and water in South America, *Hydrological Processes*, *31*(5), 972-980. doi: 10.1002/hyp.11035.

Joos, F., et al. (2013), Carbon dioxide and climate impulse response functions for the computation of greenhouse gas metrics: a multi-model analysis, *Atmospheric Chemistry and Physics*, *13*(5), 2793-2825. doi: 10.5194/acp-13-2793-2013.

Kerber, F., R. R. Querel, R. Rondanelli, R. Hanuschik, M. van den Ancker, O. Cuevas, A. Smette, J. Smoker, T. Rose, and H. Czekala (2014), An episode of extremely low precipitable water vapour over Paranal observatory, *Monthly Notices of the Royal Astronomical Society*, *439*(1), 247-255. doi: 10.1093/mnras/stt2404.

Labarca Encina, R., M. Pino, and O. Recabarren (2013), Los Lamini (Cetartiodactyla: Camelidae) extintos del yacimiento de Pilauco (Norpatagonia chilena): aspectos taxonómicos y tafonómicos preliminares, *Estudios Geologicos*, *69*(2), 255-269. doi: 10.3989/egeol.40862.219.

Lambert, F., A. Tagliabue, G. Shaffer, F. Lamy, G. Winckler, L. Farías, L. Gallardo, and R. De Pol-Holz (2015), Dust fluxes and iron fertilization in Holocene and Last Glacial Maximum climates, *Geophysical Research Letters*, *42*(14), 6014-6023. doi: 10.1002/2015GL064250.

Lamy, F., R. Gersonde, G. Winckler, O. Esper, A. Jaeschke, G. Kuhn, J. Ullermann, A. Martinez-Garcia, F. Lambert, and R. Kilian (2014), Increased dust deposition in the Pacific Southern Ocean during glacial periods, *Science*, *343*(6169), 403-407. doi: 10.1126/science.1245424.

Landais, A., et al. (2015), A review of the bipolar see–saw from synchronized and high resolution ice core water stable isotope records from Greenland and East Antarctica, *Quaternary Science Reviews*, *114*, 18-32. doi: 10.1016/j.quascirev.2015.01.031.

Lara, A., A. Bahamondez, A. González-Reyes, A. A. Muñoz, E. Cuq, and C. Ruiz-Gómez (2015), Reconstructing streamflow variation of the Baker River from tree-rings in Northern Patagonia since 1765, *Journal of Hydrology*, *529*, 511-523. doi: 10.1016/j.jhydrol.2014.12.007.

Laterra, P., P. Barral, A. Carmona, and L. Nahuelhual (2016), Focusing Conservation Efforts on Ecosystem Service Supply May Increase Vulnerability of Socio-Ecological Systems, *PloS one*, *11*(5), art0155019. doi: 10.1371/journal.pone.0155019.

Li, J., et al. (2013), El Niño modulations over the past seven centuries, *Nature Climate Change*, *3*(9), 822-826. doi: 10.1038/nclimate1936.

Lima, M., D. A. Christie, M. C. Santoro, and C. Latorre (2016), Coupled Socio-Environmental Changes Triggered Indigenous Aymara Depopulation of the Semiarid Andes of Tarapacá-Chile during the Late 19th-20th Centuries, *PloS one*, *11*(8), art0160580. doi: 10.1371/journal.pone.0160580.

Little, C., J. G. Cuevas, A. Lara, M. Pino, and S. Schoenholtz (2015), Buffer effects of streamside native forests on water provision in watersheds dominated by exotic forest plantations, *Ecohydrology*, *8*(7), 1205-1217. doi: 10.1002/eco.1575.

Lopatin, J., K. Dolos, H. J. Hernández, M. Galleguillos, and F. E. Fassnacht (2016), Comparing Generalized Linear Models and random forest to model vascular plant species richness using LiDAR data in a natural forest in central Chile, *Remote Sensing of Environment*, *173*, 200-210. doi: 10.1016/j.rse.2015.11.029.

Lucas, C., M. Ceroni, S. Baeza, A. A. Muñoz, and A. Brazeiro (2017), Sensitivity of subtropical forest and savanna productivity to climate variability in South America, Uruguay, *Journal of Vegetation Science*, *28*(1), 192-205. doi: 10.1111/jvs.12475.

Martínez-Méndez, G., D. Hebbeln, M. Mohtadi, F. Lamy, R. De Pol-Holz, D. Reyes-Macaya, and T. Freudenthal (2013), Changes in the advection of Antarctic Intermediate Water to the northern Chilean coast during the last 970 kyr, *Paleoceanography*, *28*(4), 607-618. doi: 10.1002/palo.20047.

Masiokas, M. H., et al. (2016), Reconstructing the annual mass balance of the Echaurren Norte glacier (Central Andes, 33.5° S) using local and regional hydroclimatic data, *The Cryosphere*, *10*(2), 927-940. doi: 10.5194/tc-10-927-2016.

Masotti, I., S. Belviso, L. Bopp, A. Tagliabue, and E. Bucciarelli (2016), Effects of light and phosphorus on summer DMS dynamics in subtropical waters using a global ocean biogeochemical model, *Environmental Chemistry*, *13*(2), 379-389. doi: 10.1071/EN14265.

Mastrangelo, M. E., F. Weyland, S. H. Villarino, M. P. Barral, L. Nahuelhual, and P. Laterra (2014), Concepts and methods for landscape multifunctionality and a unifying framework based on ecosystem services, *Landscape Ecology*, *29*(2), 345-358. doi: 10.1007/s10980-013-9959-9.

Mechoso, C. R., et al. (2014), Ocean–Cloud–Atmosphere–Land Interactions in the Southeastern Pacific: The VOCALS Program, *Bulletin of the American Meteorological Society*, *95*(3), 357-375. doi: 10.1175/BAMS-D-11-00246.1.

Miranda, A., A. Altamirano, L. Cayuela, F. Pincheira, and A. Lara (2015), Different times, same story: Native forest loss and landscape homogenization in three physiographical areas of south-central of Chile, *Applied Geography*, *60*, 20-28. doi: 10.1016/j.apgeog.2015.02.016.

Miranda, A., A. Altamirano, L. Cayuela, A. Lara, and M. E. González (2017), Native forest loss in the Chilean biodiversity hotspot: revealing the evidence, *Regional Environmental Change*, *17*(1), 285-297. doi: 10.1007/s10113-016-1010-7.

Mohtadi, M., M. Prange, D. W. Oppo, R. De Pol-Holz, U. Merkel, X. Zhang, S. Steinke, and A. Lückge (2014), North Atlantic forcing of tropical Indian Ocean climate, *Nature*, *509*(7498), 76-80. doi: 10.1038/nature13196.

Moisset de Espanés, P., A. Osses, and I. Rapaport (2016), Fixed-points in random Boolean networks: The impact of parallelism in the Barabási–Albert scale-free topology case, *Biosystems*, *150*, 167-176. doi: 10.1016/j.biosystems.2016.10.003.

Molina, L. T., et al. (2015), Pollution and its Impacts on the South American Cryosphere, *Earth's Future*, *3*(12), 345-369. doi: 10.1002/2015EF000311.

Molina-Montenegro, M. A., N. Ricote-Martínez, C. Muñoz-Ramírez, S. Gómez-González, C. Torres-Díaz, C. Salgado-Luarte, and E. Gianoli (2013), Positive interactions between the lichen Usnea antarctica (Parmeliaceae) and the native flora in Maritime Antarctica, *Journal of Vegetation Science*, *24*(3), 463-472. doi: 10.1111/j.1654-1103.2012.01480.x.

Montané, M., G. Cáceres, M. Villena, and R. O'Ryan (2017), Techno-Economic Forecasts of Lithium Nitrates for Thermal Storage Systems, *Sustainability*, *9*(5), art810. doi: 10.3390/su9050810.

Moreno, P. I., I. Vilanova, R. Villa-Martínez, R. D. Garreaud, M. Rojas, and R. De Pol-Holz (2014), Southern Annular Mode-like changes in southwestern Patagonia at centennial timescales over the last three millennia, *Nature Communications*, *5*, art4375. doi: 10.1038/ncomms5375.

Moreno, P. I., G. H. Denton, H. Moreno, T. V. Lowell, A. E. Putnam, and M. R. Kaplan (2015), Radiocarbon chronology of the last glacial maximum and its termination in northwestern Patagonia, *Quaternary Science Reviews*, *122*, 233-249. doi: 10.1016/j.quascirev.2015.05.027.

Moreno-Pino, M., R. D. l. Iglesia, N. Valdivia, C. Henríquez-Castilo, A. Galán, B. Díez, and N. Trefault (2016), Variation in coastal Antarctic microbial community composition at sub-mesoscale: spatial distance or environmental filtering?, *FEMS Microbiology Ecology*, *92*(7), fiw088. doi: 10.1093/femsec/fiw088.

Munoz, A., et al. (2016), Streamflow variability in the Chilean Temperate-Mediterranean climate transition (35°S–42°S) during the last 400 years inferred from tree-ring records, *Climate Dynamics*, *47*(12), 4051-4066. doi: 10.1007/s00382-016-3068-9.

Muñoz, R. C., J. Quintana, M. J. Falvey, J. A. Rutllant, and R. Garreaud (2016), Coastal Clouds at the Eastern Margin of the Southeast Pacific: Climatology and Trends, *Journal of Climate*, *29*(12), 4525-4542. doi: 10.1175/JCLI-D-15-0757.1.

Muñoz, A. A., J. Barichivich, D. A. Christie, W. Dorigo, D. Sauchyn, Á. González-Reyes, R. Villalba, A. Lara, N. Riquelme, and M. E. González (2014), Patterns and drivers of Araucaria araucana forest growth along a biophysical gradient in the northern Patagonian Andes: Linking tree rings with satellite observations of soil moisture: Patterns and drivers of Araucaria growth, *Austral Ecology*, *39*(2), 158-169. doi: 10.1111/aec.12054.

Nahuelhual, L., A. Carmona, M. Aguayo, and C. Echeverria (2014), Land use change and ecosystem services provision: a case study of recreation and ecotourism opportunities in southern Chile, *Landscape Ecology*, *29*(2), 329-344. doi: 10.1007/s10980-013-9958-x.

Nahuelhual, L., A. Carmona, P. Laterra, J. Barrena, and M. Aguayo (2014), A mapping approach to assess intangible cultural ecosystem services: The case of agriculture heritage in Southern Chile, *Ecological Indicators*, *40*, 90-101. doi: 10.1016/j.ecolind.2014.01.005.

Nahuelhual, L., F. Benra Ochoa, F. Rojas, G. I. Díaz, and A. Carmona (2016), Mapping social values of ecosystem services: What is behind the map?, *Ecology and Society*, *21*(3), art24. doi: 10.5751/ES-08676-210324.

Nahuelhual, L., P. Laterra, S. Villarino, M. Mastrángelo, A. Carmona, A. Jaramillo, P. Barral, and N. Burgos (2015), Mapping of ecosystem services: Missing links between purposes and procedures, *Ecosystem Services*, *13*, 162-172. doi: 10.1016/j.ecoser.2015.03.005.

Neukom, R., M. Rohrer, P. Calanca, N. Salzmann, C. Huggel, D. Acuña, D. A. Christie, and M. S. Morales (2015), Facing unprecedented drying of the Central Andes? Precipitation variability over the period AD 1000–2100, *Environmental Research Letters*, *10*(8), art084017. doi: 10.1088/1748-9326/10/8/084017.

Osborn, T. J., J. Barichivich, I. Harris, G. van der Schrier, and P. D. Jones (2016), Monitoring global drought using the self-calibrating Palmer Drought Severity Index, *State of the Climate 2015, Bulletin of the American Meteorological Society*, *97*(8), S32-S36. doi: 10.1175/2016BAMSStateoftheClimate.1.

Osorio, D., J. M. Capriles, P. C. Ugalde, K. Herrera, C. Salas, M. Sepulveda, E. M. Gayo, C. Latorre, D. Jackson, and C. M. Santoro (2017), Hunter-Gatherer Mobility Strategies in the High Andes of northern Chile during the late Pleistocene-early Holocene Transition (ca. 11,500-9,500 CAL B.P.), *Journal of Field Archaeology*, *In press*, 1-13. doi: 10.1080/00934690.2017.1322874.

Osses, A., L. Gallardo, and T. Faundez (2013), Analysis and evolution of air quality monitoring networks using combined statistical information indexes, *Tellus B: Chemical and Physical Meteorology*, *65*(1), art19822. doi: 10.3402/tellusb.v65i0.19822.

Parada, C., et al. (2016), South Pacific Integrated Ecosystem Studies meeting: toward conservation and sustainable use of marine resources in the South Pacific, *Fisheries Oceanography*, *25*, 1-4. doi: 10.1111/fog.12148.

Perez-Quezada, J. F., C. E. Brito, J. Cabezas, M. Galleguillos, J. P. Fuentes, H. E. Bown, and N. Franck (2016), How many measurements are needed to estimate accurate daily and annual soil respiration fluxes? Analysis using data from a temperate rainforest, *Biogeosciences*, *13*(24), 6599-6609. doi: 10.5194/bg-13-6599-2016.

Pesce, O. H., and P. I. Moreno (2014), Vegetation, fire and climate change in central-east Isla Grande de Chiloé (43°S) since the Last Glacial Maximum, northwestern Patagonia, *Quaternary Science Reviews*, *90*, 143-157. doi: 10.1016/j.quascirev.2014.02.021.

Pino, M., M. Chávez-Hoffmeister, X. Navarro-Harris, and R. Labarca (2013), The late Pleistocene Pilauco site, Osorno, south-central Chile, *Quaternary International*, *299*, 3-12. doi: 10.1016/j.quaint.2012.05.001.

Pino, P., V. Iglesias, R. Garreaud, S. Cortés, M. Canals, W. Folch, S. Burgos, K. Levy, L. P. Naeher, and K. Steenland (2015), Chile Confronts its Environmental Health Future After 25 Years of Accelerated Growth, *Annals of Global Health*, *81*(3), 354-367. doi: 10.1016/j.aogh.2015.06.008.

Power, M. J., et al. (2013), Climatic control of the biomass-burning decline in the Americas after ad 1500, *The Holocene*, *23*(1), 3-13. doi: 10.1177/0959683612450196.

Rahn, D. A., and R. D. Garreaud (2014), A synoptic climatology of the near-surface wind along the west coast of South America, *International Journal of Climatology*, *34*(3), 780-792. doi: 10.1002/joc.3724.

Rojas, M. (2013), Sensitivity of Southern Hemisphere circulation to LGM and 4 × CO2 climates, *Geophysical Research Letters*, *40*(5), 965-970. doi: 10.1002/grl.50195.

Rojas, M., P. A. Arias, V. Flores-Aqueveque, A. Seth, and M. Vuille (2016), The South American monsoon variability over the last millennium in climate models, *Climate of the Past*, *12*(8), 1681-1691. doi: 10.5194/cp-12-1681-2016.

Rojas, M., C. Mac-Lean, J. Morales, A. Monares, and R. Fustos (2016), Climate change education and literacy at the Faculty of Physical and Mathematical Sciences of the University of Chile, *International Journal of Global Warming*, *in press*, 1-19.

Rojas, M., L. Z. Li, M. Kanakidou, N. Hatzianastassiou, G. Seze, and H. L. Treut (2013), Winter weather regimes over the Mediterranean region: their role for the regional climate and projected changes in the twenty-first century, *Climate Dynamics*, *41*(3), 551-571. doi: 10.1007/s00382-013-1823-8.

Romero-Lankao, P., S. Hughes, A. Rosas-Huerta, R. Borquez, and D. M. Gnatz (2013), Institutional Capacity for Climate Change Responses: An Examination of Construction and Pathways in Mexico City and Santiago, *Environment and Planning C: Government and Policy*, *31*(5), 785-805. doi: 10.1068/c12173.

Romero-Lankao, P., S. Hughes, H. Qin, J. Hardoy, A. Rosas-Huerta, R. Borquez, and A. Lampis (2014), Scale, urban risk and adaptation capacity in neighborhoods of Latin American cities, *Habitat International*, *42*, 224-235. doi: 10.1016/j.habitatint.2013.12.008.

Romero-Mieres, M., M. E. González, and A. Lara (2014), Recuperación natural del bosque siempreverde afectado por tala rasa y quema en la Reserva Costera Valdiviana, Chile, *Bosque*, *35*(3), 257-267. doi: 10.4067/S0717-92002014000300001.

Rondanelli, R., A. Molina, and M. Falvey (2015), The Atacama Surface Solar Maximum, *Bulletin of the American Meteorological Society*, *96*(3), 405-418. doi: 10.1175/BAMS-D-13-00175.1.

Ronge, T. A., R. Tiedemann, F. Lamy, P. Köhler, B. V. Alloway, R. De Pol-Holz, K. Pahnke, J. Southon, and L. Wacker (2016), Radiocarbon constraints on the extent and evolution of the South Pacific glacial carbon pool, *Nature Communications*, *7*, art11487. doi: 10.1038/ncomms11487.

Rubio, M., E. Lissi, E. Gramsch, and R. Garreaud (2015), Effect of Nearby Forest Fires on Ground Level Ozone Concentrations in Santiago, Chile, *Atmosphere*, *6*(12), 1926-1938. doi: 10.3390/atmos6121838.

Rutllant, J. A., R. C. Muñoz, and R. D. Garreaud (2013), Meteorological observations on the northern Chilean coast during VOCALS-REx, *Atmospheric Chemistry and Physics*, *13*(6), 3409-3422. doi: 10.5194/acp-13-3409-2013.

Saide, P. E., M. Mena-Carrasco, S. Tolvett, P. Hernandez, and G. R. Carmichael (2016), Air quality forecasting for winter-time PM 2.5 episodes occurring in multiple cities in central and southern Chile, *Journal of Geophysical Research: Atmospheres*, *121*(1), 558-575. doi: 10.1002/2015JD023949.

Santoro, C. M., et al. (2016), Continuities and discontinuities in the socio-environmental systems of the Atacama Desert during the last 13,000 years, *Journal of Anthropological Archaeology*, *in press*, 1-12. doi: 10.1016/j.jaa.2016.08.006.

Scaff, L., J. A. Rutllant, D. Rahn, S. Gascoin, and R. Rondanelli (2017), Meteorological Interpretation of Orographic Precipitation Gradients along an Andes West Slope Basin at 30°S (Elqui Valley, Chile), *Journal of Hydrometeorology*, *18*(3), 713-727. doi: 10.1175/JHM-D-16-0073.1.

Schefuß, E., T. I. Eglinton, C. L. Spencer-Jones, J. Rullkötter, R. De Pol-Holz, H. M. Talbot, P. M. Grootes, and R. R. Schneider (2016), Hydrologic control of carbon cycling and aged carbon discharge in the Congo River basin, *Nature Geoscience*, *9*(9), 687-690. doi: 10.1038/ngeo2778.

Seguel, R. J., C. A. Mancilla, R. Rondanelli, M. A. Leiva, and R. G. E. Morales (2013), Ozone distribution in the lower troposphere over complex terrain in Central Chile, *Journal of Geophysical Research: Atmospheres*, *118*(7), 2966-2980. doi: 10.1002/jgrd.50293.

Shaffer, G. (2014), Formulation, calibration and validation of the DAIS model (version 1), a simple Antarctic ice sheet model sensitive to variations of sea level and ocean subsurface temperature, *Geoscientific Model Development*, *7*(4), 1803-1818. doi: 10.5194/gmd-7-1803-2014.

Shaffer, G., M. Huber, R. Rondanelli, and J. O. Pepke Pedersen (2016), Deep time evidence for climate sensitivity increase with warming, *Geophysical Research Letters*, *43*(12), 6538-6545. doi: 10.1002/2016GL069243.

Siani, G., E. Michel, R. De Pol-Holz, T. DeVries, F. Lamy, M. Carel, G. Isguder, F. Dewilde, and A. Lourantou (2013), Carbon isotope records reveal precise timing of enhanced Southern Ocean upwelling during the last deglaciation, *Nature Communications*, *4*, art2758. doi: 10.1038/ncomms3758.

Stern, C. R., P. I. Moreno, W. I. Henríquez, R. Villa-Martínez, E. Sagredo, J. C. Aravena, and R. De Pol-Holz (2016), Holocene tephrochronology around Cochrane (~ 47 S), southern Chile, *Andean Geology*, *43*(1), 1-19. doi: 10.5027/andgeoV43n1-a01.

Swanson, F. J., J. A. Jones, C. M. Crisafulli, and A. Lara (2013), Effects of volcanic and hydrologic processes on forest vegetation: Chaitén Volcano, Chile, *Andean Geology*, *40*(2), 359-391. doi: 10.5027/andgeoV40n2-a10.

Swanson, F. J., J. Jones, C. Crisafulli, M. E. González, and A. Lara (2016), Puyehue-Cordón Caulle eruption of 2011: tephra fall and initial forest responses in the Chilean Andes, *Bosque*, *37*(1), 85-96. doi: 10.4067/S0717-92002016000100009.

Titschack, J., D. Baum, R. de Pol-Holz, M. López Correa, N. Forster, S. Flögel, D. Hebbeln, and A. Freiwald (2015), Aggradation and carbonate accumulation of Holocene Norwegian cold-water coral reefs, *Sedimentology*, *62*(7), 1873-1898. doi: 10.1111/sed.12206.

Ugalde, P. C., C. M. Santoro, E. M. Gayo, C. Latorre, S. Maldonado, R. De Pol-Holz, and D. Jackson (2015), How Do Surficial Lithic Assemblages Weather in Arid Environments? A Case Study from the Atacama Desert, Northern Chile, *Geoarchaeology*, *30*(4), 352-368. doi: 10.1002/gea.21512.

Ulrich, W., et al. (2014), Climate and soil attributes determine plant species turnover in global drylands, *Journal of biogeography*, *41*(12), 2307-2319. doi: 10.1111/jbi.12377.

Urquiza, A., and B. Morales (2015), La observación del problema ambiental en un contexto de diferenciación funcional, *Revista Mad**(33), 64-93. doi: 10.5354/0718-0527.2015.37324.

Urrutia-Jalabert, R., Y. Malhi, and A. Lara (2015), The Oldest, Slowest Rainforests in the World? Massive Biomass and Slow Carbon Dynamics of Fitzroya cupressoides Temperate Forests in Southern Chile, *PloS one*, *10*(9), art0137569. doi: 10.1371/journal.pone.0137569.

Urrutia-Jalabert, R., Y. Malhi, and A. Lara (2017), Soil respiration and mass balance estimation of fine root production in <i>Fitzroya cupressoides</i> forests of southern Chile, *Ecosphere*, *8*(4), art01640. doi: 10.1002/ecs2.1640.

Urrutia-Jalabert, R., S. Rossi, A. Deslauriers, Y. Malhi, and A. Lara (2015), Environmental correlates of stem radius change in the endangered Fitzroya cupressoides forests of southern Chile, *Agricultural and Forest Meteorology*, *200*, 209-221. doi: 10.1016/j.agrformet.2014.10.001.

Urrutia-Jalabert, R., Y. Malhi, J. Barichivich, A. Lara, A. Delgado-Huertas, C. G. Rodríguez, and E. Cuq (2015), Increased water use efficiency but contrasting tree growth patterns in Fitzroya cupressoides forests of southern Chile during recent decades, *Journal of Geophysical Research: Biogeosciences*, *120*(12), 2505-2524. doi: 10.1002/2015JG003098.

Valenzuela, D., C. M. Santoro, J. M. Capriles, M. J. Quinteros, R. Peredo, E. M. Gayo, I. Montt, and M. Sepúlveda (2015), Consumption of animals beyond diet in the Atacama Desert, northern Chile (13,000–410BP): Comparing rock art motifs and archaeofaunal records, *Journal of Anthropological Archaeology*, *40*, 250-265. doi: 10.1016/j.jaa.2015.09.004.

van der Schrier, G., J. Barichivich, I. Harris, P. D. Jones, and T. J. Osborn (2015), Monitoring global drought using the self-calibrating Palmer Drought Severity Index, *State of the Climate 2014, Bulletin of the American Meteorological Society*, *96*(7), S30-S31.

Van den Hoof, C., and F. Lambert (2016), Mitigation of Drought Negative Effect on Ecosystem Productivity by Vegetation Mixing, *Journal of Geophysical Research: Biogeosciences*, *121*(10), 2667-2683. doi: 10.1002/2016JG003625

10.1002/2016jg003625 </div>.

Veblen, T. T., M. E. González, G. Stewart, T. Kitzberger, and J. Brunet (2016), Tectonic ecology of the temperate forests of South America and New Zealand, *New Zealand Journal of Botany*, *54*(2), 223-246. doi: 10.1080/0028825X.2015.1130726.

Verdugo, J., E. Damm, P. Snoeijs, B. Díez, and L. Farías (2016), Climate relevant trace gases (N2O and CH4) in the Eurasian Basin (Arctic Ocean), *Deep Sea Research Part I: Oceanographic Research Papers*, *117*, 84-94. doi: 10.1016/j.dsr.2016.08.016.

Viale, M., and R. Garreaud (2014), Summer Precipitation Events over the Western Slope of the Subtropical Andes, *Monthly Weather Review*, *142*(3), 1074-1092. doi: 10.1175/MWR-D-13-00259.1.

Viale, M., and R. Garreaud (2015), Orographic effects of the subtropical and extratropical Andes on upwind precipitating clouds, *Journal of Geophysical Research: Atmospheres*, *120*(10), 4962-4974. doi: 10.1002/2014JD023014.

Villalobos, A. M., F. Barraza, H. Jorquera, and J. J. Schauer (2017), Wood burning pollution in southern Chile: PM2.5 source apportionment using CMB and molecular markers, *Environmental Pollution*, *In Press*. doi: 10.1016/j.envpol.2017.02.069.

von Glasow, R., et al. (2013), Megacities and Large Urban Agglomerations in the Coastal Zone: Interactions Between Atmosphere, Land, and Marine Ecosystems, *AMBIO*, *42*(1), 13-28. doi: 10.1007/s13280-012-0343-9.

Vuille, M., E. Franquist, R. D. Garreaud, W. Sven, L. Casimiro, and B. Cáceres (2015), Impact of the global warming hiatus on Andean temperature, *Journal of Geophysical Research: Atmospheres*, *120*(9), 3745-3757. doi: 10.1002/2015JD023126.

Yevenes, M. A., J. L. Arumí, and L. Farías (2016), Unravel biophysical factors on river water quality response in Chilean Central-Southern watersheds, *Environmental Monitoring and Assessment*, *188*(5), 264-281. doi: 10.1007/s10661-016-5235-1.

Yevenes, M. A., K. Soetaert, and C. M. Mannaerts (2016), Tracing Nitrate-Nitrogen Sources and Modifications in a Stream Impacted by Various Land Uses, South Portugal, *Water*, *8*(9), art385. doi: 10.3390/w8090385.

Yevenes, M. A., E. Bello, S. Sanhueza-Guevara, and L. Farías (2016), Spatial Distribution of Nitrous Oxide (N2O) in the Reloncaví Estuary–Sound and Adjacent Sea (41°–43° S), Chilean Patagonia, *Estuaries and Coasts*, *published online*, 1-15. doi: 10.1007/s12237-016-0184-z.

Zambrano-Bigiarini, M., A. Nauditt, C. Birkel, K. Verbist, and L. Ribbe (2017), Temporal and spatial evaluation of satellite-based rainfall estimates across the complex topographical and climatic gradients of Chile, *Hydrology and Earth System Sciences*, *21*(2), 1295-1320. doi: 10.5194/hess-21-1295-2017.

Zhao, Y., et al. (2016), Detailed dynamic land cover mapping of Chile: Accuracy improvement by integrating multi-temporal data, *Remote Sensing of Environment*, *183*, 170-185. doi: 10.1016/j.rse.2016.05.016.

Zickfeld, K., et al. (2013), Long-Term Climate Change Commitment and Reversibility: An EMIC Intercomparison, *Journal of Climate*, *26*(16), 5782-5809. doi: 10.1175/JCLI-D-12-00584.1.

11. Non ISI Publications

- ✓ For each publication, if applicable, the principal author and the corresponding author must be indicated using the following terminology:
  - 1 For principal author (example: Toro1, J.)
  - 2 For the corresponding author (example: Toro2, J.)
  - 3 For principal and corresponding author (example: Toro3, J.)
- ✓ Include a digital copy of each **PUBLISHED** paper that has not been sent to CONICYT in past reports.

- ✓ Carrasco, C., J. Karstensen, and L. Farias (2017), On the Nitrous Oxide Accumulation in Intermediate Waters of the Eastern South Pacific Ocean, *Frontiers in Marine Science*, *4*, art24. doi: 10.3389/fmars.2017.00024.
- ✓ Garreaud, R., and M. Viale (2014), Análisis de los fenómenos meteorológicos y climáticos que afectan la cuenca del río Maipo, *Aquae Papers*, *5*, 17-29.

- ✓ Kugler, N. R., and P. Moraga Sariego (2016), "Climate change damages", conceptualization of a legal notion with regard to reparation under international law, *Climate Risk Management*, *13*, 103-111. doi: 10.1016/j.crm.2016.06.004.
- ✓ LeQuesne, C., M. Rojas, and D. A. Christie (2015), Anillos de crecimiento de Austrocedrus chilensis: un archivo natural del cambio climático, *Revista del Jardin Botánico Chagual*, *12*, 31-35.
- ✓ Maljean-Dubois, S., and P. Moraga Sariego (2014), Le principe des responsabilités communes mais différenciées dans le régime international du climat, *Les Cahiers de droit*, *55*(1), 83-112. doi: 10.7202/1025500ar.
- ✓ Moraga Sariego, P. (2017), La Definición de Nuevos Estándares en Materia de Participación Ciudadana en el Sistema de Evaluación de Impacto Ambiental, *IN PRESS Revista Derecho del Estado*(38), 1-22. doi: TBD.
- ✓ Moraga Sariego, P., and S. Mieckevi (2017), Análisis crítico de la judicialización del cambio climático y la economía baja en carbono frente a las categorías tradicionales del derecho, *Revista de Derecho, Universidad de Concepción*, 1-15.
- ✓ Muñoz, F. (2016), Conocimiento Climático y Redes de Datos Meteorológicos ¿Por qué necesitamos monitorear el clima?, *Bits de Ciencia*(14), 35-41.
- ✓ Rondanelli, R. (2017), ¿Cómo llueve cuando llueve en Atacama ?, *PRP "Generación de información y monitoreo del Fenómeno El Niño" - IGP*, *4*(3), 4-6.
- ✓ Salazar, D., I. Corral, P. Corrales, S. Avilés, A. Escudero, D. Estévez, C. Flores, C. Oyarzo, and C. Palma (2016), ¿Ocupaciones tardías del Complejo Cultural Bato en Maitencillo? Implicancias para la trayectoria histórica de las poblaciones del litoral de Chile Central, *IN PRESS Boletín de la Sociedad Chilena de Arqueología*, *46*, 1-27 TBD.
- ✓ Smith-Ramírez, C., M. E. González, C. Echeverría, and A. Lara (2015), Estado actual de la Restauración ecológica en Chile, perspectivas y desafíos, *Anales del Instituto de la Patagonia*, *43*(1), 11-21. doi: 10.4067/S0718-686X2015000100002.

12. Books and book chapters

- ✓ Include a hard copy of every **PUBLISHED** book that has not been sent to CONICYT in past reports.
- ✓ Include a digital copy of the front page of the chapter in the case of a book chapter that has not been sent to CONICYT in past reports.

- ✓ (2014), *La Organización de las Organizaciones Sociales: aplicaciones desde perspectivas sistemicas*, 496 pp., RIL EDITORES, Santiago, Chile.
- ✓ (2014), *Ecología Forestal: Bases para un manejo sustentable de los Bosques Nativos*, 730 pp., Marisa Cuneo Editores, Valdivia, Chile.
- ✓ Adler, C., P. Aldunce, K. Indvik, D. Alegría, R. Borquez, and V. Galaz (2015), Resilience, in *Research handbook on climate governance*, edited by K. Bäckstrand and E. Lövbrand, pp. 491-502, Edward Elgar Publishing, Cheltenham, UK Northampton, MA, USA.
- ✓ Aldunce, P., V. Levin, and A. León (2013), Disaster risk reduction informing climate change adaptation: Social Capital in Aguita de la Perdiz, n. 29, in *A changing environment for human security: transformative approaches to research, policy and action*, edited by L. Sygna, K. L. O'Brien and J. Wolf, pp. 336-346, Routledge, London, UK.
- ✓ Benedetti, A., et al. (2014), Operational Dust Prediction, in *Mineral Dust*, edited by P. Knippertz and J. W. Stuut, pp. 223-265, Springer Netherlands, Dordrecht.
- ✓ Blanco, G. (2016), Abriendo la caja negra del Cambio Climático: Claves para comprender su trayectoria política en América Latin, in *Cambio Ambiental Global, Estado y Valor Público: La Cuestión Socio-Ecológica en América Latina, entre Justicia Ambiental y "Legítima" Depredación.*, edited by A. Lampis, pp. 45-66, Centro de Estudios Sociales (CES), Consejo Latinoamericano de Ciencias Sociales (CLACSO), Pontificia Universidad Católica de Perú (PUCP), Universidad Nacional de Colombia. Bogotá.
- ✓ Cárcamo, M., A. Lara, L. Palma, M. Lavado, D. Roco, and R. Bravo (2013), Proyecto Innova Cuencas APR; Una oportunidad para generar condiciones habilitantes para el desarrollo de comunidades rurales: Hacia la construcción de un modelo de gestión de cuencas en la región de Los Ríos, Chile, in *Servicios Ecosistémicos*

hídricos: estudios de caso en América Latina y el Caribe, edited by A. Lara, P. Laterra, R. Manson and G. Barrantes, pp. 169-185, Red ProAgua CYTED Imprenta América, Valdivia, Chile.

- ✓ Díez, B., and K. Ininbergs (2013), Ecological importance of cyanobacteria, in *Cyanobacteria: An Economic Perspective*, edited by N. K. Sharma, A. K. Rai and L. J. Stal, pp. 41-63, John Wiley & Sons, Ltd, Chichester, UK.
- ✓ Gallardo, L., O. L. Mayol-Bracero, and L. C. Belalcazar (2016), Key Message 1, in *Integrated Assessment of Short-Lived Climate Pollutants for Latin America and the Caribbean: Improving air quality while mitigating climate change. Summary for decision makers*, edited by G. Raga and P. Artaxo, pp. 8-9, United Nations Environment Programme, Nairobi, Kenya.
- ✓ Gonzalez, M. E. (2014), Post-fire passive restoration of Andean Araucaria-Nothofagus forests, in *Genetic Considerations in Ecosystem Restoration using native tree species.*, edited by M. Bozzano, R. Jalonen, E. Thomas, D. Boshier, L. Gallo, S. Cavers, S. Bordács, P. Smith and J. Loo, pp. 151-156, Food and Agriculture Organizations of the United Nations and Bioversity International, Rome, Italy.
- ✓ Gonzalez, M. E., et al. (2014), Ecología de disturbios y su influencia en los ecosistemas forestales templados de Chile y Argentina, in *Ecología Forestal: Bases para un manejo sustentable de los Bosques Nativos*, edited by P. J. Donoso, M. E. Gonzalez and A. Lara, pp. 411-504, Marisa Cuneo Editores, Valdivia, Chile.
- ✓ Lara, A., C. A. Little, M. E. Gonzalez, and D. Lobos (2013), Restauración de bosques nativos para aumentar la provisión de agua como un servicio ecosistémico en el centro-sur de Chile: desde las pequeñas cuencas a la escala de paisaje, in *Servicios Ecosistémicos hídricos: estudios de caso en América Latina y el Caribe*, edited by A. Lara, P. Laterra, R. Manson and G. Barrantes, pp. 57-78, Red ProAgua CYTED Imprenta América, Valdivia, Chile.
- ✓ Lara, A., C. Zamorano-Elqueta, A. Miranda, M. E. Gonzalez, and R. Reyes (2016), Bosques Nativos, in *Informe País: Estado del medio ambiente en Chile. Comparación 1999-2015*, edited by N. Gligo, pp. 167-219, Centro de Análisis de Políticas Públicas del Instituto de Asuntos Públicos de la Universidad de Chile, Santiago, Chile.
- ✓ Lara, A., M. Amoroso, C. Donoso, M. E. Gonzalez, G. R. Vargas, C. Smith-Ramírez, G. Arellano, and A. G. Gutierrez (2014), Sucesión y Dinámica de Bosques Templados en Chile, in *Ecología Forestal: Bases para un manejo sustentable de los Bosques Nativos*, edited by P. J. Donoso, M. E. Gonzalez and A. Lara, pp. 323-410, Marisa Cuneo Editores, Valdivia, Chile.
- ✓ Lara, A., C. Little, M. Cortés, E. Cruz, M. E. Gonzalez, C. Echeverria, J. Suarez, A. Bahamondez, and R. E. Coopman (2014), Restauración de ecosistemas forestales, in *Ecología Forestal: Bases para un manejo sustentable de los Bosques Nativos*, edited by P. J. Donoso, M. E. Gonzalez and A. Lara, pp. 605-672, Marisa Cuneo Editores, Valdivia, Chile.
- ✓ Lazzarino, S., S. Otero, N. Pohl, and N. Tondreau (2016), Comunica tu Ciencia, in *Simposio de Comunicación Científica. Comunicación científica como profesión, formación, responsabilidades y roles*, edited by A. Umaña and A. León, pp. 258-261, Vicerrectoría de Investigación, Universidad Estatal a Distancia, San José, Costa Rica.
- ✓ Little, C., and A. Lara (2014), Servicios ecosistémicos de los bosques nativos del centro sur de Chile, in *Ecología Forestal: Bases para un manejo sustentable de los Bosques Nativos*, edited by P. J. Donoso, M. E. Gonzalez and A. Lara, pp. 323-408, Marisa Cuneo Editores, Valdivia, Chile.
- ✓ Little, C. A., A. Lara, and M. E. Gonzalez (2013), Temperate Rainforest Restoration in Chile (Virtual Field Trip), in *Ecological restoration: principles, values, and structure of an emerging profession*, edited by A. F. Clewell and J. Aronson, pp. 190-196, Island Press, Washington, DC, USA.
- ✓ Little, C., M. Zambrano-Bigiarini, S. Benitez, and A. Rivera (2016), Aguas Continentales, in *Informe País: Estado del medio ambiente en Chile. Comparación 1999-2015*, edited by N. Gligo, pp. 115-166, Centro de Análisis de Políticas Públicas del Instituto de Asuntos Públicos de la Universidad de Chile, Santiago, Chile.
- ✓ Masson-Delmotte, V., et al. (2014), Information from Paleoclimate Archives, in *Climate Change 2013 - The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by T. F. Stocker, D. Qin, G. K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley, pp. 383-464, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

- ✓ McPhee, J., G. Cortés, M. Rojas, L. Garcia, A. Descalzi, and L. Vargas (2014), Downscaling Climate Changes for Santiago: What Effects can be Expected?, in *Climate Adaptation Santiago*, edited by K. Krellenberg and B. Hansjürgens, pp. 19-41, Springer Berlin Heidelberg, Berlin, Heidelberg.
- ✓ Moraga Sariego, P. (2013), Energía, desarrollo sustentable y derecho internacional, in *Energía, cambio climático y sustentabilidad: una mirada desde el derecho*, edited by P. Moraga Sariego, pp. 255-266, LegalPublishing : Thomson Reuters, Santiago, Chile.
- ✓ Moraga Sariego, P. (2014), Regards sur certaines conventions environnementales en droit chilien : une contribution au développement d'une économie «bas-carbone», in *Contrat et environnement*, edited by M. Boutonnet, pp. 145-156, Bruylant, Paris, France.
- ✓ Moraga Sariego, P., et al. (2015), *El principio precautorio en el derecho comparado*, 210 pp., Editorial Gráfica LOM, Chile.
- ✓ Nahuelhual, L., P. Laterra, A. Carmona, N. Burgos, A. Jaramillo, O. Barral, M. Mastrangelo, and S. Villarino (2013), Evaluación y mapeo de servicios ecosistémicos: Una revisión y análisis de enfoques metodológicos, in *Servicios Ecosistémicos hídricos: estudios de caso en América Latina y el Caribe*, edited by A. Lara, P. Laterra, R. Manson and G. Barrantes, pp. 11-28, Red ProAgua CYTED Imprenta América, Valdivia, Chile.
- ✓ Oryan, R., and C. Ibarra (2017), Environmental Policy in Latin America, in *Global Encyclopedia of Public Administration, Public Policy, and Governance*, edited by A. Farazmand, pp. 1-9, Springer International Publishing, Cham, Switzerland.
- ✓ Santoro, C., et al. (2016), Capítulo 3: Cazadores, Recolectores y pescadores Arcaicos del Desierto de Atacama. Entre el Pacífico y los Andes, Norte de Chile, in *Prehistoria en Chile: desde sus primeros habitantes hasta los Incas*, edited by F. Falabella, M. Uribe, L. Sanhueza, C. Aldunate and J. Hidalgo, pp. 117-180, Editorial Universitaria, Santiago,Chile.
- ✓ Silva-Pinto, V., E. M. Gayo, and D. Garcia-Salazar (2017), Uso de Isotopos Estables, in *Manual de Arqueometría*, edited by R. Chapoulie, M. Sepulveda, N. Del Solar and V. Wright, pp. 1-31, Instituto Francés de Estudios Andinos, Lima, Perú.
- ✓ Stocker, T. F., et al. (2014), Technical Summary, in *Climate Change 2013 - The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by T. F. Stocker, D. Qin, G. K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley, pp. 33-115, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- ✓ Stocker, T. F., et al. (2014), Summary for Policymakers, in *Climate Change 2013 - The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by T. F. Stocker, D. Qin, G. K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley, pp. 1-30, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- ✓ Urquiza, A. (2014), Resiliencia y adaptación en sistemas organizacionales, in *La Organización de las Organizaciones Sociales: aplicaciones desde perspectivas sistemicas.*, edited by H. Cadenas, M. Arnoldo and A. Urquiza, pp. 171-187, RIL EDITORES, Santiago, Chile.
- ✓ Villarroel, S. (2013), Gestión estratégica de stakeholders en un proyecto de energías renovables no convencionales: Lecciones del caso del proyecto eólico Chiloé, in *Energía, cambio climático y sustentabilidad: una mirada desde el derecho*, edited by P. Moraga Sariego, pp. 125-150, LegalPublishing : Thomson Reuters, Santiago, Chile.

13. Patents

- ✓ Include all patents generated by the FONDAP Center.

14. Congress presentations

- ✓ Include abstracts of all presentations. Attach a digital copy of the front page of the congress/workshop book that has not been sent to CONICYT in past reports.

15. Organization of Scientific Meetings

- ✓ List all congresses, courses, conferences, symposia, or workshops organized by the FONDAP Center.
- ✓ Include abstracts of all presentations. Attach a digital copy of the front page of the congress/workshop book that has not been sent to CONICYT in past reports.

16. Collaborative Activities

- ✓ List the scientific visits of Center members to international institutions
- ✓ List the scientific visits of foreign researchers to the Center in Chile.

17. Postdoctoral Fellows

- ✓ List postdoctoral fellows working in the Center during the reported period regardless of their funding sources.
- ✓ Provide current affiliation and positions held by former postdoctoral fellows that left the Center during the reported period

18. Students

- ✓ List titles of theses framed in the project completed during the reported period. Attach an abstract and the subject index.
- ✓ List titles of theses in progress, framed in the project, during the reported period. Include digital copies of the corresponding thesis registrations.
- ✓ Provide current affiliation and positions held by former students that graduated during the reported period

19. Funding Sources

- ✓ List all funding sources including FONDAP.