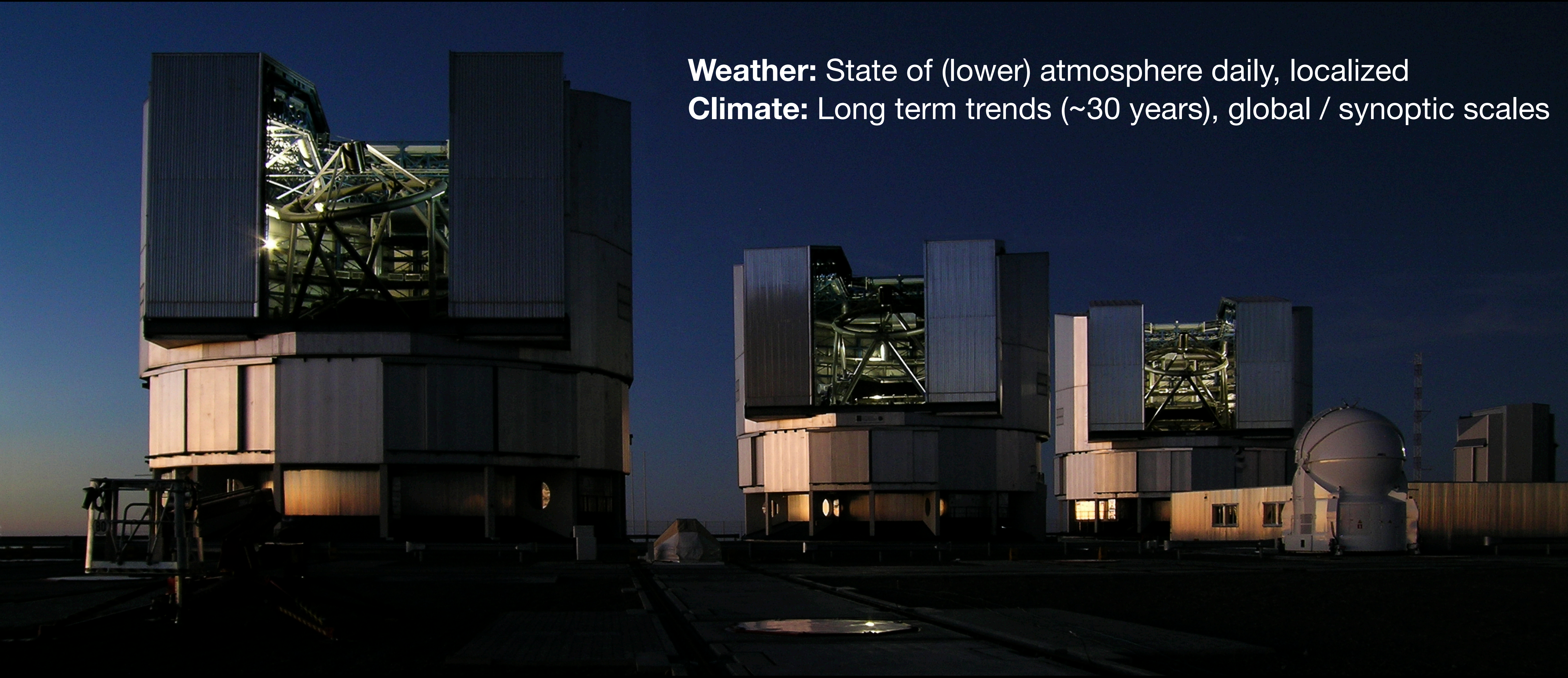
Impact of climate change in astronomy

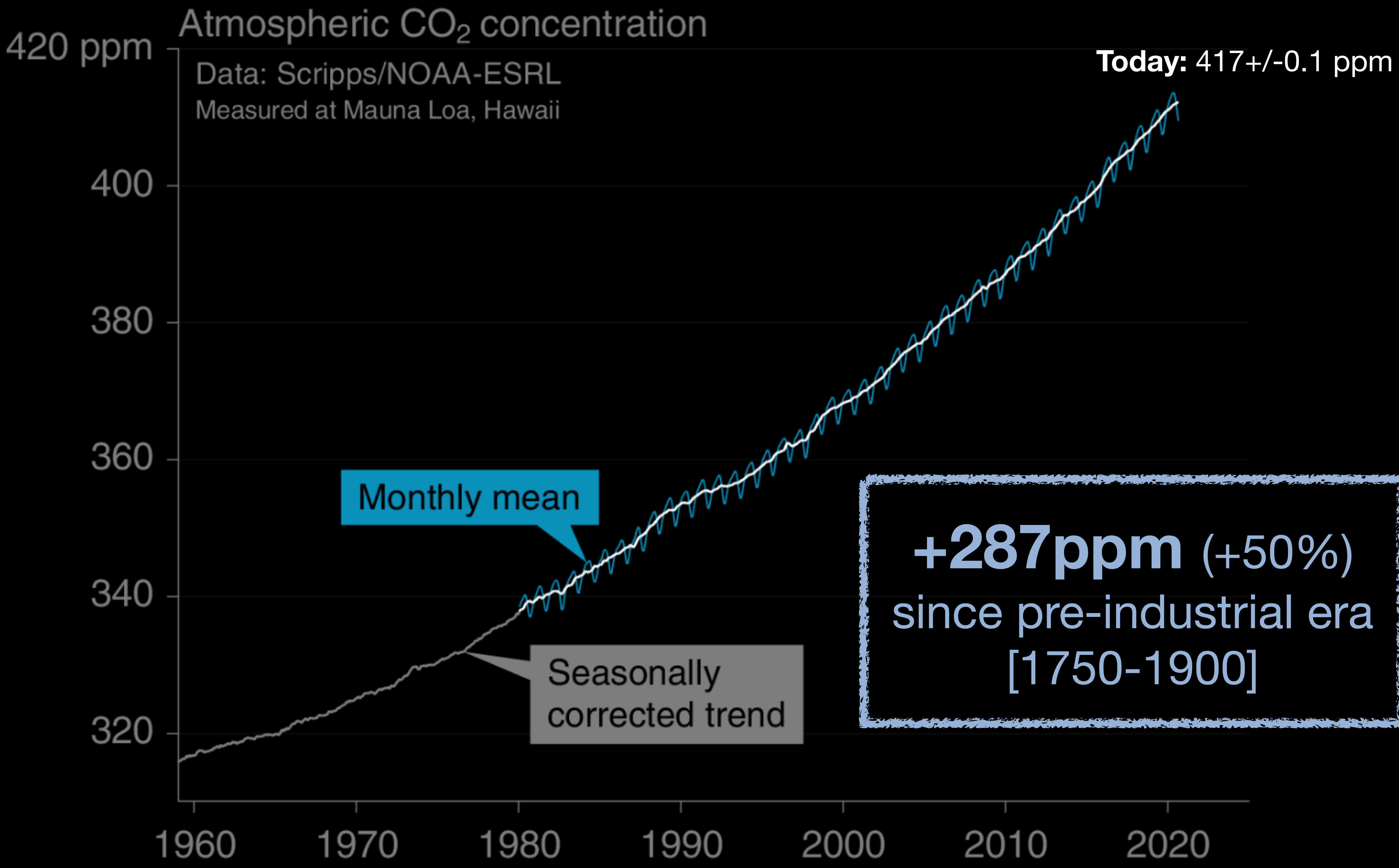


Weather: State of (lower) atmosphere daily, localized
Climate: Long term trends (~30 years), global / synoptic scales

Faustine CANTALLOUBE, LAM

Julien MILLI, ESO/IPAG Grenoble
Marc SARAZIN, ESO Garching
Kira REHFELD, Heidelberg Center for Environment (HCE)
Susanne CREWELL, Institute for Meteorology and Geophysics (IMGW)
Stefanie Fiedler, Institute for Meteorology and Geophysics (IMGW)
et al.

Climate: where we stand ?

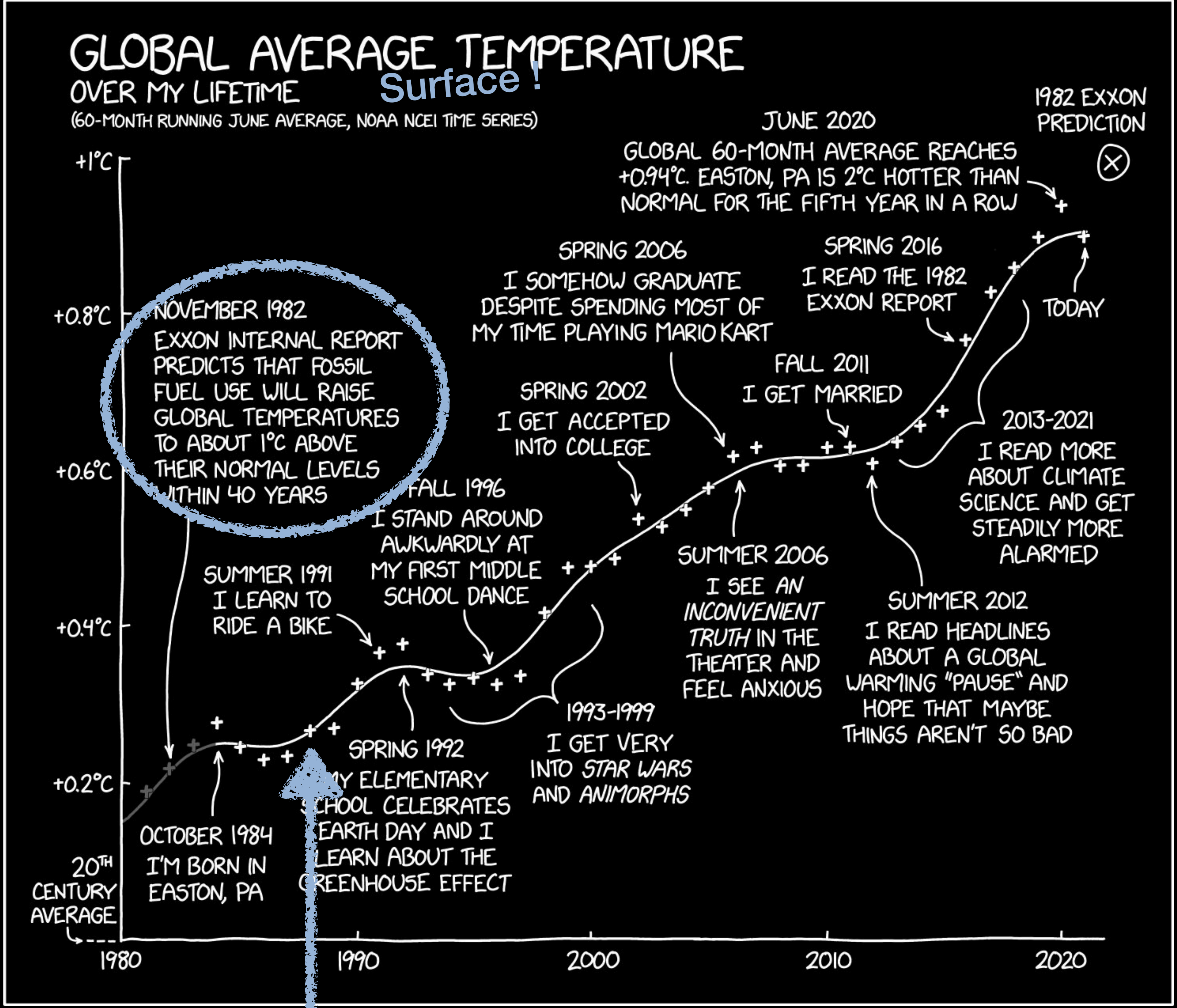


Today: 417+/-0.1 ppm

+287ppm (+50%)
since pre-industrial era
[1750-1900]

Also called Keeling curve

Climate: where we stand ?



© xkcd.com

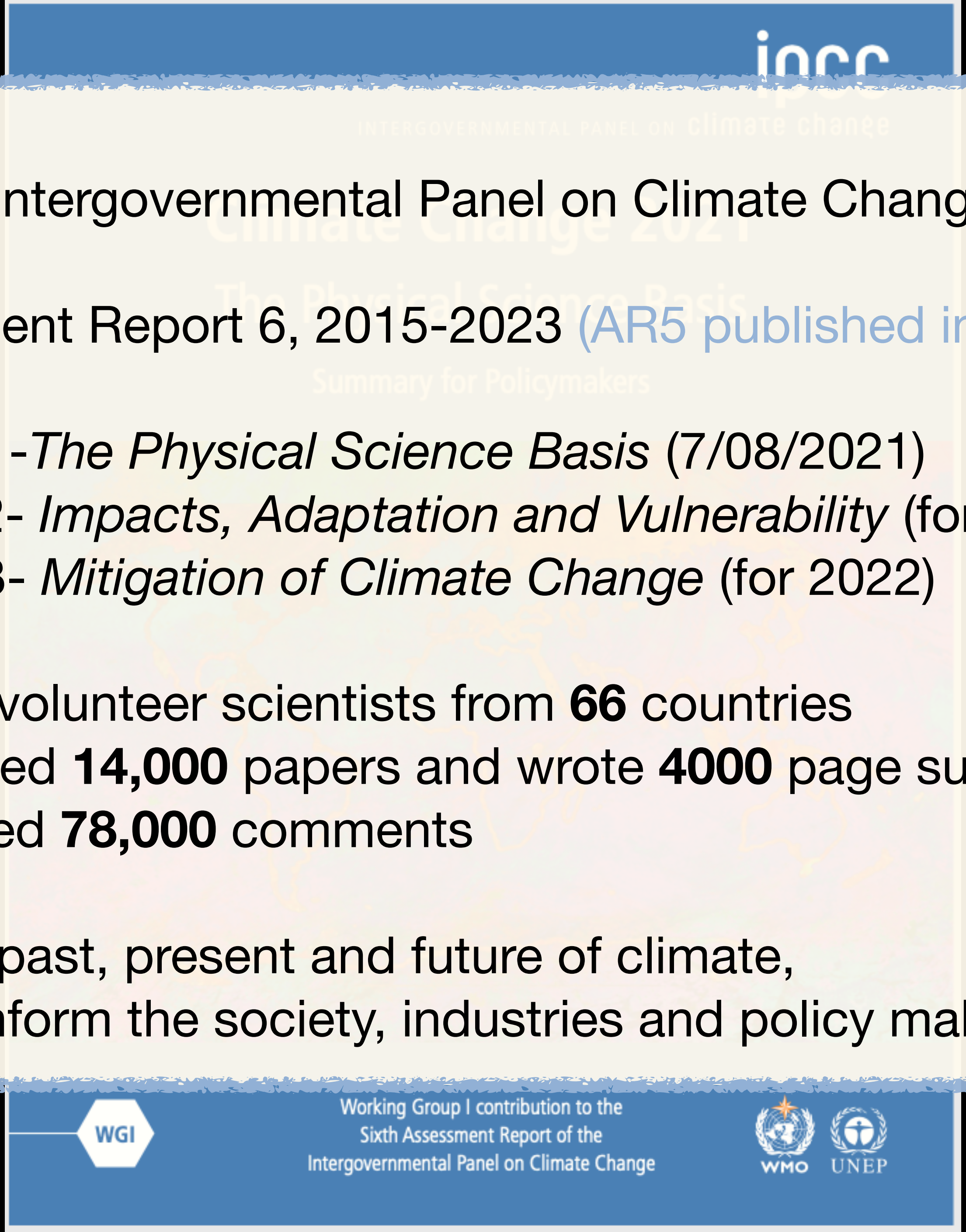
Today:
1.1+/-0.1◦C

IPCC is founded !

(and I'm born)

IPCC - AR6 report from WG1

The physical science basis



ipcc
INTERGOVERNMENTAL PANEL ON climate change

Climate Change 2021
The Physical Science Basis
Summary for Policymakers

WGI
Working Group I contribution to the
Sixth Assessment Report of the
Intergovernmental Panel on Climate Change

WMO UNEP

IPCC (GIEC): Intergovernmental Panel on Climate Change

AR6: Assessment Report 6, 2015-2023 (AR5 published in 2014)

WGs: WG1-*The Physical Science Basis* (7/08/2021)
WG2- *Impacts, Adaptation and Vulnerability* (for 2022)
WG3- *Mitigation of Climate Change* (for 2022)

WG1: **234** volunteer scientists from **66** countries
Reviewed **14,000** papers and wrote **4000** page summary report
Received **78,000** comments

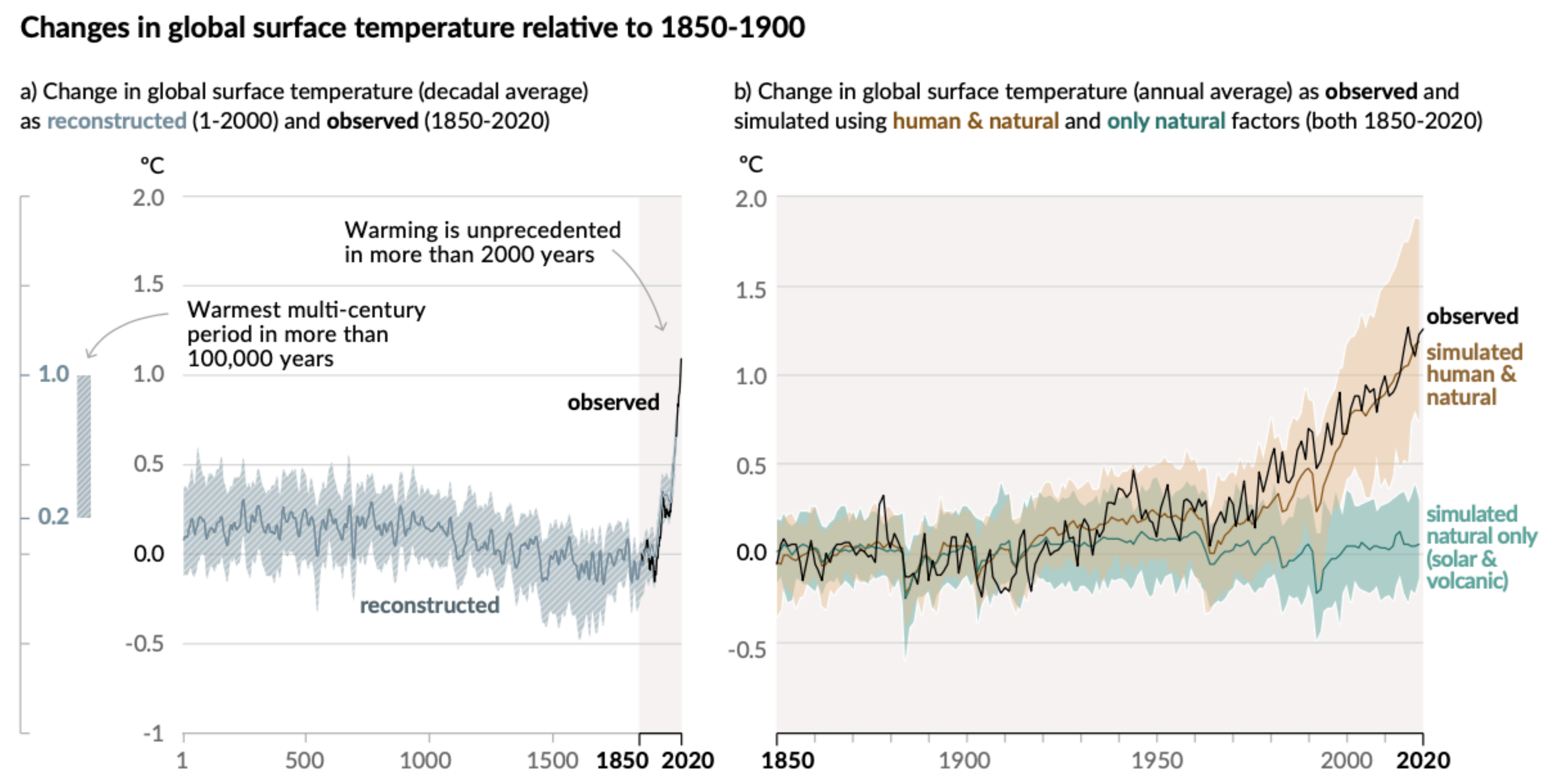
Rational: The past, present and future of climate,
to inform the society, industries and policy makers

Summary for Policy Makers, 42 pages
https://www.ipcc.ch/report/ar6/wg1/#SPM

IPCC - AR6 report from WG1

A. The Current State of the Climate

A.1 Human influence has warmed atmosphere, oceans and lands
A.2 The scale of recent changes is unprecedented over 100-1000 years
A.3 It already affects weather & climate extremes everywhere
A.4 Improve knowledge on processes makes us understand better radiative forcing



Changes in global surface temperature relative to 1850-1900

a) Change in global surface temperature (decadal average) as reconstructed (1-2000) and **observed** (1850-2020)

b) Change in global surface temperature (annual average) as **observed** and simulated using human & natural and only natural factors (both 1850-2020)

Warming is unprecedented in more than 2000 years

Warmest multi-century period in more than 100,000 years

IPCC - AR6 report from WG1

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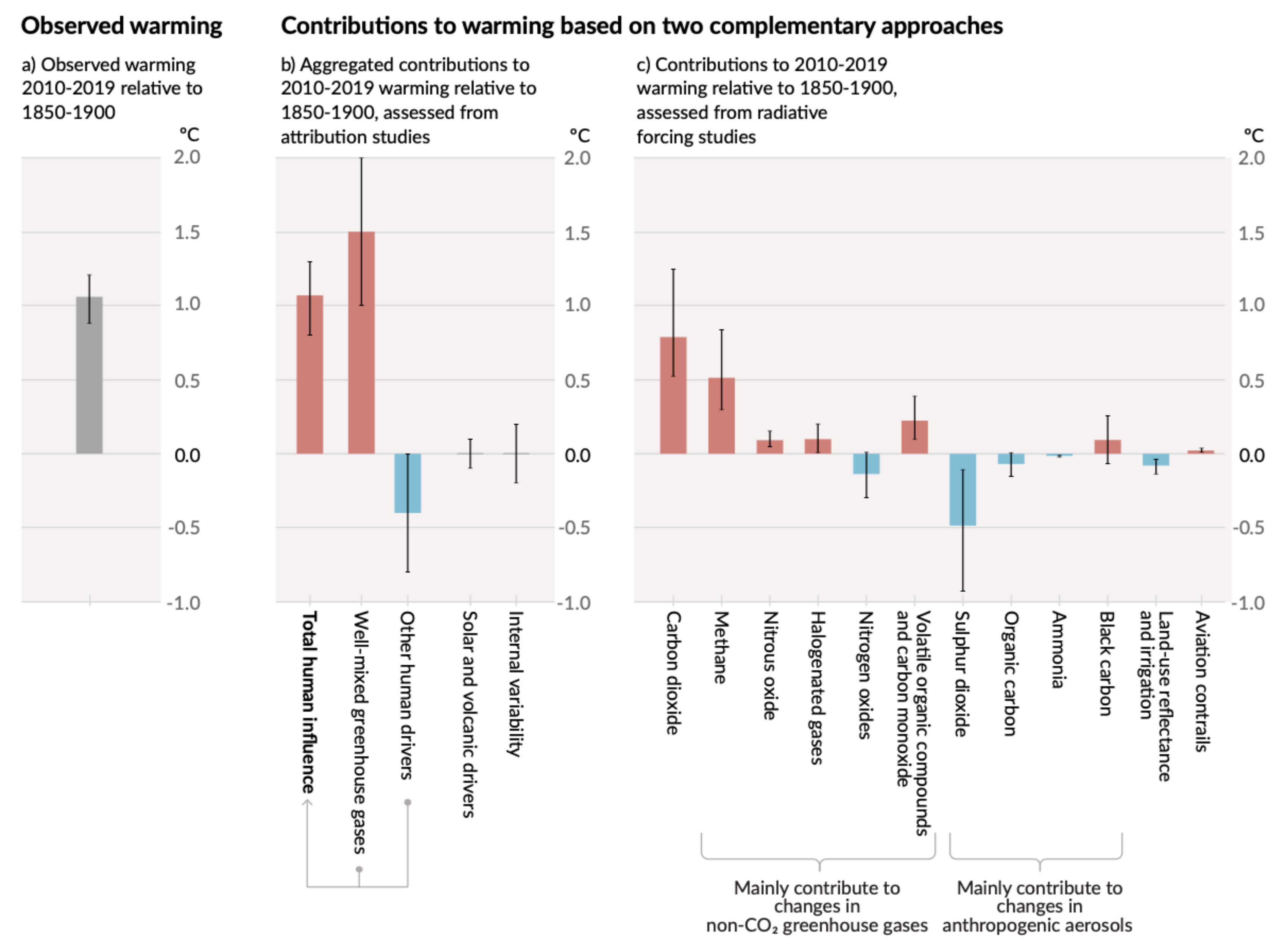

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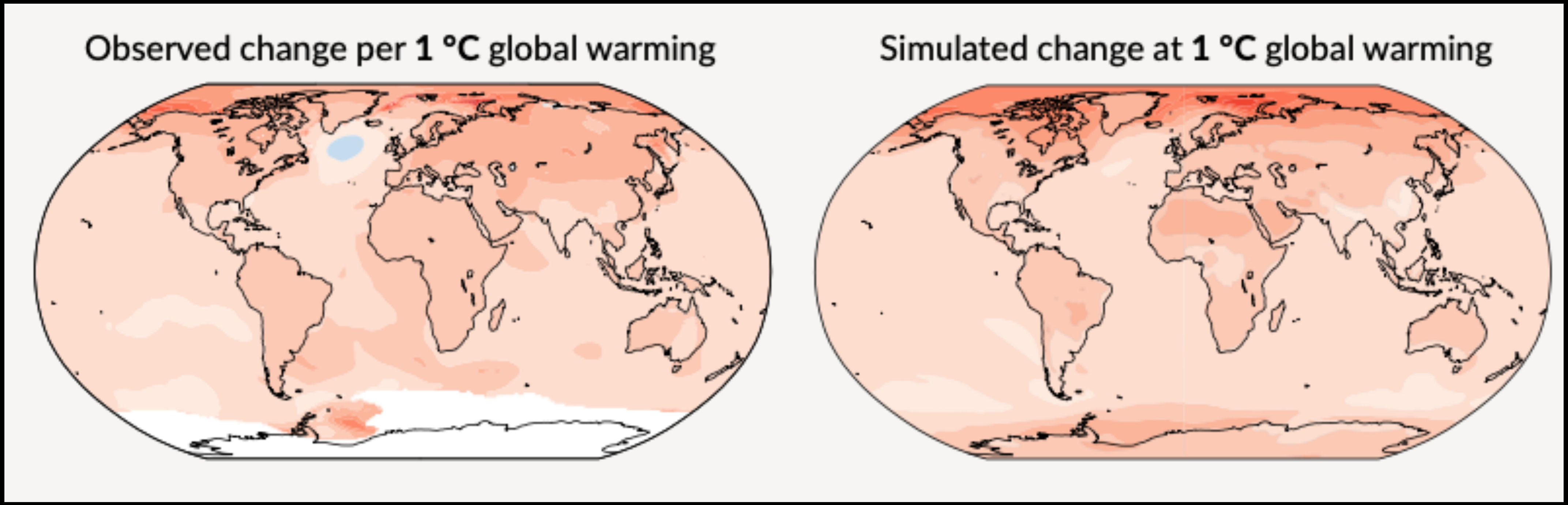
B. Possible Climate Futures

B.1 Temperature will continue rising until at least 2050 - 2◦C will be exceeded
B.2 Many changes become larger (e.g. intensity and frequency of extreme weather events, ice loss…)
B.3 It affects water cycle (intensification variability, wet & dry, monsoon…)
B.4 As atmospheric CO2 increases, the carbon sinks (lands and oceans) are less efficient
B.5 Most changes are irreversible for centuries or millennials



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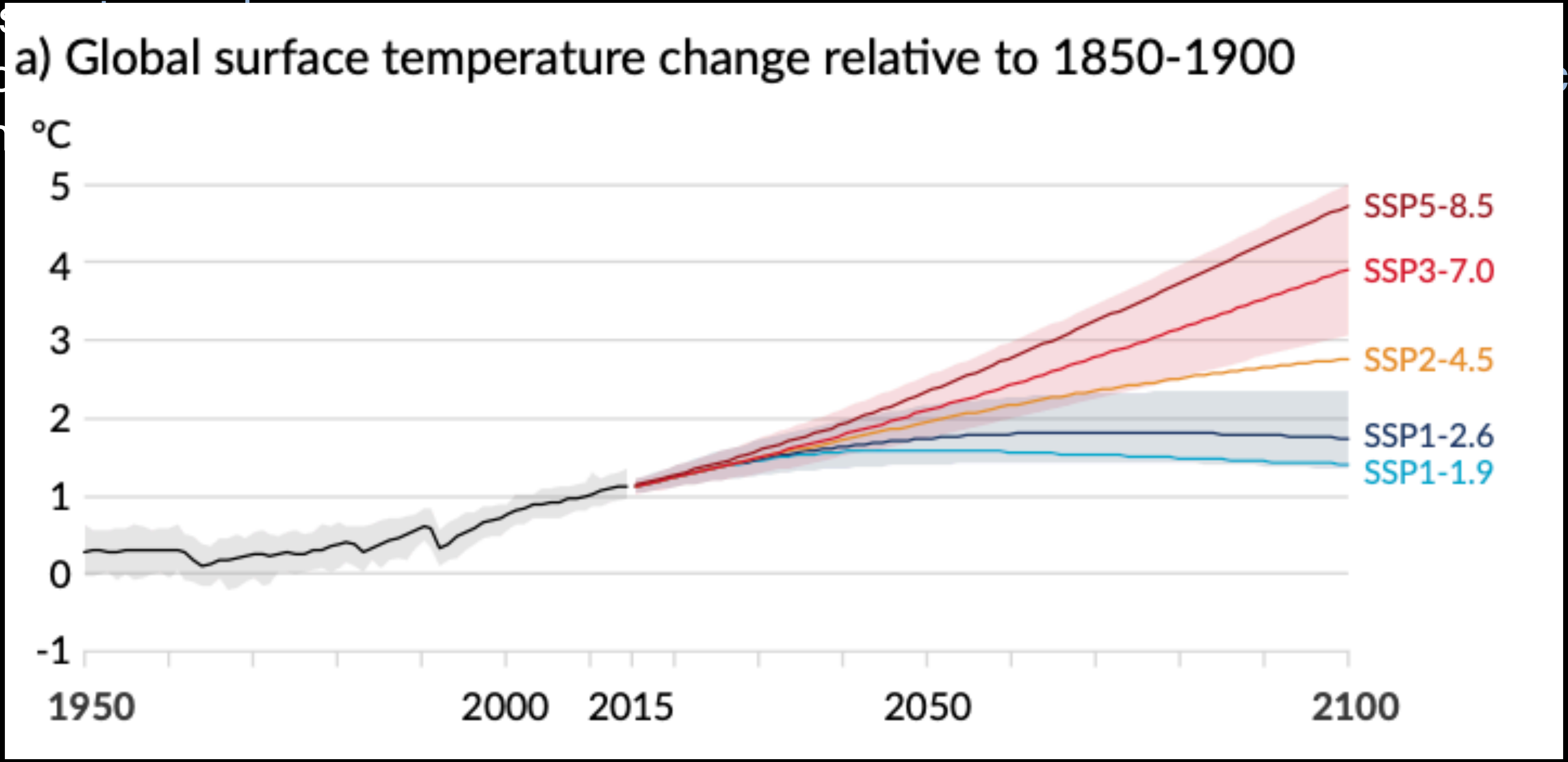

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C. Climate Information for Risk Assessment and Regional Adaptation

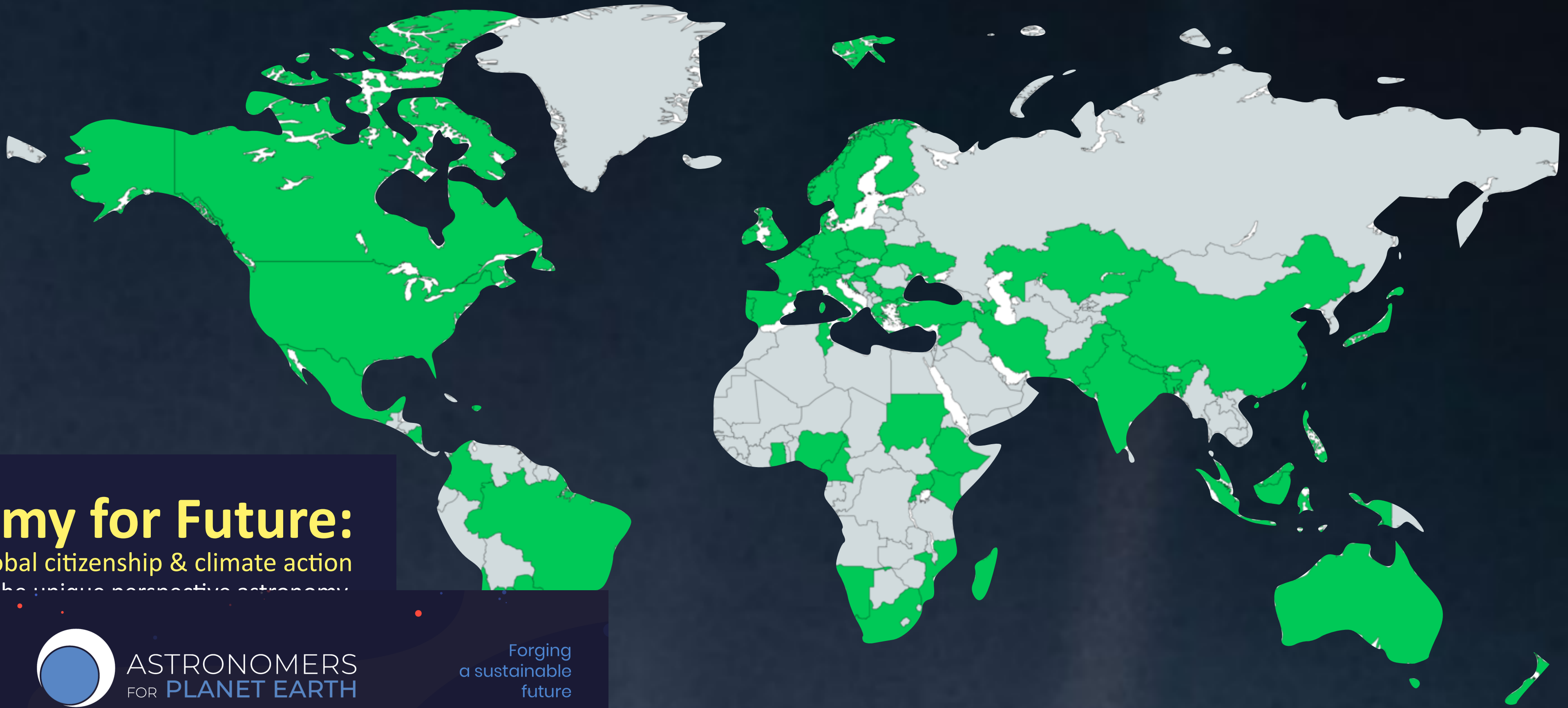
C.1 Modulation by natural drivers & internal variability can affect significantly, amplify or attenuate
C.2 Higher warming means wider spread in Climate Impact Drivers changes
C.3 Tipping point cannot be ruled out !

D. Limiting Future Climate Change

D.1 Strong, rapid and sustained reduction of GHG is needed + we need to reach net-zero CO2
D.2 Whatever the scenario, within 20-years, temperature trends will be above natural variability

Astronomers for Planet Earth

ASTRONOMERS
FOR PLANET EARTH



Astronomy for Future:

Development, global citizenship & climate action

Join us to discuss th

provid

Mon 29 June - Special S
Tues 30 June - Lunch Se
European Astronomical

Invited speakers

Didier Barret (Institut de Recherch
Astrophysique et Planétologie)
Sandra Benitez Herrera (Institu
Astrofísica de Canarias)
Luis Calçada (European Southern
Faustine Cantalloube (Max Plan
Astronomy)
Jaime E. Forero-Romero (Unive
Andes)
Stefania Giodini (Red Cross Data
Rachel Grange (ETH Zürich)
James Hansen (Colombia Univers

Scientific organisers

Chairs: Michelle Willebrands, Leo Bu
Abijheet Borkar, Andreas Burkert, Ke
Vanessa McBride, George Miley, Dav

ASTRONOMERS
FOR PLANET EARTH

Forging
a sustainable
future

Join us to discuss the unique perspective astronomy provides on our own Planet

Thu, 1 July
Special Session (SS30)

Fri, 2 July
Lunch Session (SS30)

eas.unige.ch
European Astronomical Society
Annual Meeting 2021, Leiden

Invited speakers

Alison Anderson (University of Plymouth)
Clarisse Aujoux (Sorbonne Université, Paris)
Lewis Ball (SKAO)
Xavier Barcons (ESO)
Olivier Berné (IRAP, Toulouse)
Claudia Cicone (University of Oslo)
Hannah Dalgleish (University of Oxford)
Debra Fisher (Yale University)
Sara Lucatello (INAF, Padova)
Michael Mann (Penn State)
Robert Massey (Royal Astronomical Society)
Vanessa Moss (CSIRO)
Kimberly Nicholas (Lund University)
Karen Olson (Steward Observatory, Arizona)
Matthias Steinmetz (AIP Potsdam)
Sarah White (Rhodes University)
Andy Williams (ESO)

PANEL DISCUSSION

"The future of the EAS annual meeting"

Sara Lucatello
(INAF Padova; EAS Vice President)
Johan Knapen
(IAC Tenerife; member of the EAS meeting board)
Vanessa Moss
(CSIRO)
Huub Röttgering
(Leiden observatory; chair of the EAS hosting committee 2020/2021)
Joop Schaye
(Leiden observatory; chair of the EAS SOC 2020/2021)
Sarah White
(Rhodes University; EAS inclusion committee)

Scientific organisers

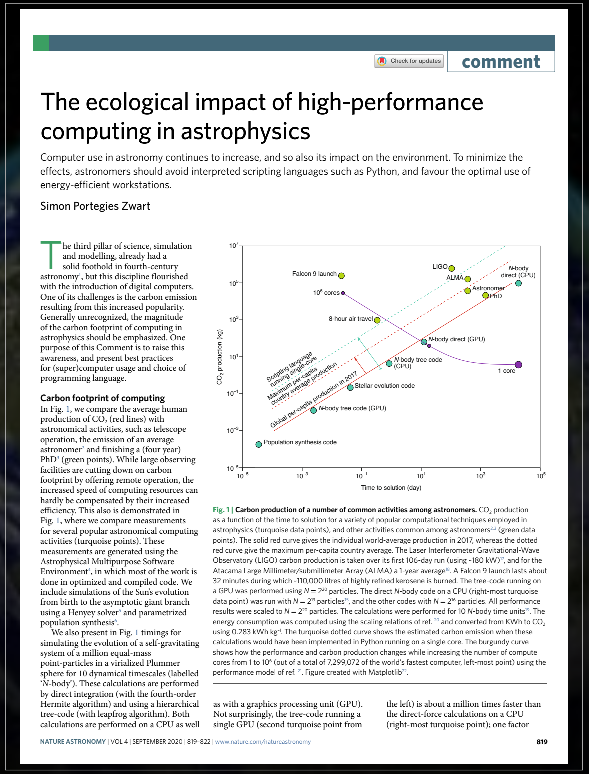
Leo Burtscher (co-chair), Hannah Dalgleish (co-chair), Tobias Beuchert, Faustine Cantalloube, Victoria Grinberg, Natasha Hurley-Walker, Mathieu Isidro, Knud Jahnke, Michelle Willebrands

eas 2021 Leiden Virtual

This, is our home

Sign our Open Letter !
https://astronomersforplanet.earth/open-letter

Nature Astronomy, 'Climate Issue' 2020


comment

The ecological impact of high-performance computing in astrophysics

Computer use in astronomy continues to increase, and so also its impact on the environment. To minimize the effects, astronomers should avoid interpreted scripting languages such as Python, and favour the optimal use of energy-efficient workstations.

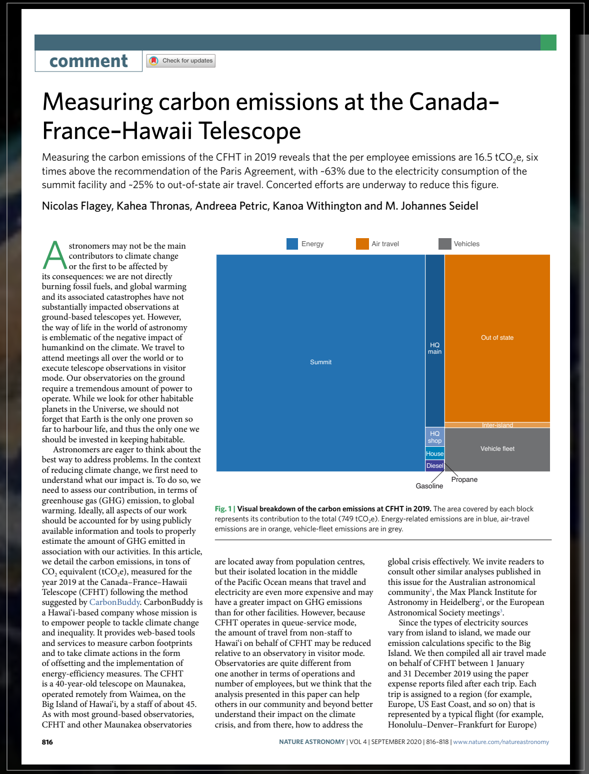
Simon Portegies Zwart


comment

An astronomical institute's perspective on meeting the challenges of the climate crisis

Analysing greenhouse gas emissions of an astronomical institute is a first step to reducing its environmental impact. Here, we break down the emissions of the Max Planck Institute for Astronomy in Heidelberg and propose measures for reductions.

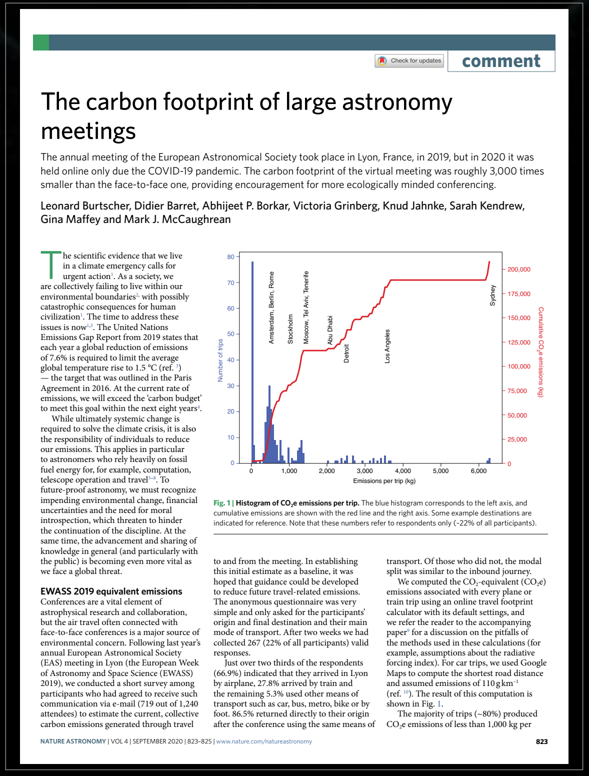
Knud Jahnke, Christian Fendt, Morgan Fouesneau, Iskren Georgiev, Tom Herbst, Melanie Kaasinen, Diana Kossakowski, Jan Rybizki, Martin Schlecker, Gregor Seidel, Thomas Henning, Laura Kreidberg and Hans-Walter Rix


comment

Measuring carbon emissions at the Canada–France–Hawaii Telescope

Measuring the carbon emissions of the CFHT in 2019 reveals that the per employee emissions are 16.5 tCO$_2$e, six times above the recommendation of the Paris Agreement, with ~63% due to the electricity consumption of the summit facility and ~25% to out-of-state air travel. Concerted efforts are underway to reduce this figure.

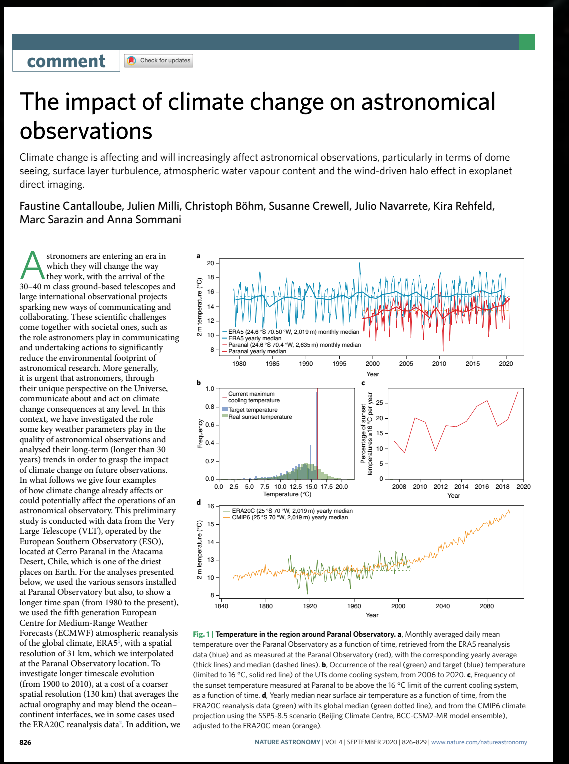
Nicolas Flagey, Kahea Thronas, Andreea Petric, Kanoa Withington and M. Johannes Seidel


comment

The carbon footprint of large astronomy meetings

The annual meeting of the European Astronomical Society took place in Lyon, France, in 2019, but in 2020 it was held online only due the COVID-19 pandemic. The carbon footprint of the virtual meeting was roughly 3,000 times smaller than the face-to-face one, providing encouragement for more ecologically minded conferencing.

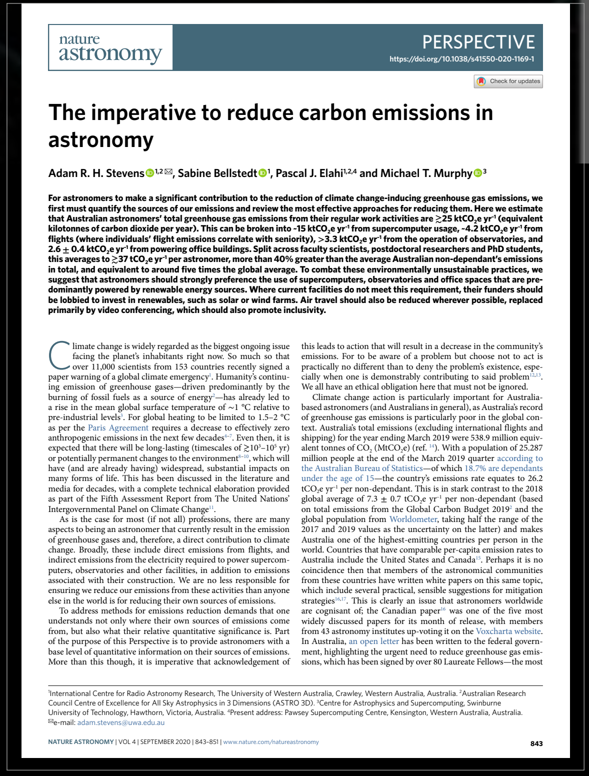
Leonard Burtscher, Didier Barret, Abhijeet P. Borkar, Victoria Grinberg, Knud Jahnke, Sarah Kendrew, Gina Maffey and Mark J. McCaughrean


comment

The impact of climate change on astronomical observations

Climate change is affecting and will increasingly affect astronomical observations, particularly in terms of dome seeing, surface layer turbulence, atmospheric water vapour content and the wind-driven halo effect in exoplanet direct imaging.

Faustine Cantalloube, Julien Milli, Christoph Böhm, Susanne Crewell, Julio Navarrete, Kira Rehfeld, Marc Sarazin and Anna Sommani


nature astronomy

PERSPECTIVE

https://doi.org/10.1038/s41550-020-1169-1

The imperative to reduce carbon emissions in astronomy

Adam R. H. Stevens, Sabine Bellstedt, Pascal J. Elahi and Michael T. Murphy

https://rdcu.be/b61Oh

https://rdcu.be/b61Oi

https://rdcu.be/b61On

https://rdcu.be/b61Or

https://rdcu.be/b61Ok

https://rdcu.be/b61Of

©University illustration / Michael Osadciw

Nature Astronomy, 'Climate Issue' 2021

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https://rdcu.be/cxPAG

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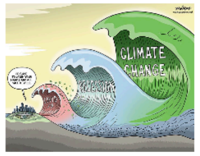
editorial

Climate change continues to be an issue

As the world recovers from one global crisis, it must steel itself for the coming of a far greater one: the climate crisis. Astronomers and planetary scientists have roles to play as trusted scientific experts, but should seek partnerships with domain experts when venturing outside their areas of knowledge.

The COVID-19 pandemic has been a stark reminder of humanity's close links to the 'natural' world. Despite advanced knowledge of virology, immunology, medicine and crisis response techniques, the human species has experienced more than 4 million deaths following infection by a virus that arose naturally (according to best current knowledge). The situation could have been worse, however, and governments around the world did act to mitigate the impact on lives. These measures set an important precedent for action from civil authorities and international cooperation in the future. It is now clear that another global disaster is heading our way and already making its effects felt: the climate crisis. It is inevitable that global temperatures will rise as a consequence of human pollution of the planet over the last two and a half centuries, and particularly over the last 50 years. "Nature does not bargain and you cannot compromise with the laws of physics," warns climate activist Greta Thunberg.

While the initial efforts of some astrophysicists to model the COVID-19 outbreak were criticized in some quarters, the climates of terrestrial planets is a domain where astronomers and planetary scientists have extensive knowledge and expertise. This provides astronomers with a unique viewpoint on Earth's climate crisis, and we should certainly communicate our understanding of this topic to the wider public, especially given our abundant opportunities to engage in public outreach, appear in the media, and teach hundreds of thousands of students every



Credit: Graeme MacKay

It should be stated quite clearly that there is no way to 'fix' the climate crisis. It is unavoidable that the planet will warm, and there will be environmental consequences of that warming: heatwaves, heavy precipitation, droughts, coastal flooding and tropical cyclones. Last month the Intergovernmental Panel on Climate Change released their latest report, which made it clear that there are opportunities to limit the extent of environmental impact if action is taken immediately, though, and future outcomes will depend on the degree of action taken. The report focuses on limiting global cumulative CO_2 emissions, reaching at least net zero, and ideally also reducing emissions of other greenhouse gases such as CH_4. But it does not explain how to limit CO_2 emissions; that will be for governments and intergovernmental organizations to decide. In November this year, hundreds of politicians and world

NATO policy advisor Andrew Williams has distilled his experience in this arena into a Comment in this issue. Again, the advice is to work with the experts.

Exactly a year ago we dedicated our September 2020 issue to presenting the quantitative impact of astronomy as a profession on the environment. Some of the numbers presented in the various articles were surprising: attending a large European astronomy conference generates as much CO_2 per capita as a year of everyday life in a developing country; the average Australian astronomer, just through their professional activities, generates 40% more CO_2 than a typical Australian, with senior astronomers being the biggest contributors; and the footprint of European astronomers is not much smaller. These articles and some of the others in the issue raised awareness within the community of astronomy's carbon footprint, and the topic was discussed widely in journal clubs and departmental and board meetings. The Astronomers for Planet Earth group, which was formed off the back of the large European astronomy conference mentioned above, has been keeping the momentum going, engaging in a number of activities detailed in another Comment in the current issue. Organizations such as the European Southern Observatory and the Square Kilometre Array Observatory have been putting forth their sustainability plans. Professional astronomy can exist in a low-carbon future, but changes must be made, from removing the dependence of our observatories and supercomputers

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comment

Forging a sustainable future for astronomy

The climate crisis is no longer a prediction for the future, it is happening here and now. Astronomers have realized that they need to become part of the solution and are working towards reducing their own carbon footprint as well as communicating an astronomical perspective.

Leonard Burtscher, Hannah Dalgleish, Didier Barret, Tobias Beuchert, Abhijeet Borkar, Faustine Cantalloube, Abigail Frost, Victoria Grinberg, Natasha Hurley-Walker, Violette Impellizzeri, Mathieu Isidro, Knud Jahnke and Michelle Willebrands

The climate crisis is real and humans are causing it[1]: the urgency of these scientific facts is becoming increasingly clear. Developing nations such as low-lying Bangladesh have experienced the impacts of climate change with devastating floods in recent years[2], while richer nations in the global north suffer record wildfires[3], heatwaves and floods. Indeed, a study[4] conducted earlier this year by the Yale Program on Climate Change Communication found that internationally, a large majority of people have understood that everyone is vulnerable in a deteriorating climate, and encourages immediate and significant action. And yet, current climate action is too little and too slow to reduce emissions quickly enough to keep within 1.5 °C of global heating, the goal of the 2015 Paris Agreement. More awareness, and more action, is essential. Fundamentally it is governments and corporations that must act, but actions by individuals and groups have power too, especially when they come from wealthy people whose contributions to greenhouse gas emissions are disproportionally large (Fig. 1).

The carbon footprint of astronomers is substantial, too. For instance, the average emissions associated with visiting a single in-person conference are similar to the annual per capita emissions of developing countries[5]. And yet astronomers can contribute to solving the climate crisis in two key ways. Firstly, by demonstrating how global collaboration is possible without burning fossil fuels, and secondly, through communicating the climate crisis from an astronomical perspective[6–8].

Discussing, and reducing, our own emissions as astronomers is vital for a number of reasons. The most fundamental is the moral argument: we know that our emissions are causing harm, so reducing them is the ethical choice. But we also need to reduce emissions for our own discipline's sake[9] (Fig. 2). Countries signing up to net-zero targets necessitate the need to perform carbon-neutral research; the sooner we prepare, the better we will manage the transition for our own discipline. Finally, we need to reduce emissions in order to make ourselves credible actors in the much larger societal fight against the climate crisis. How can we convincingly tell the general public and policy makers that 'there is no planet B' while hopping onto the next intercontinental flight for a conference at a fancy location?

To support both climate action within astronomy and to help astronomers communicate the climate crisis, the grass-roots organization Astronomers for Planet Earth (A4E) was founded in 2019. In two years, A4E has rapidly grown to a global organization connecting more than 1,100 research astronomers, astronomy educators, and students[7]. A4E members

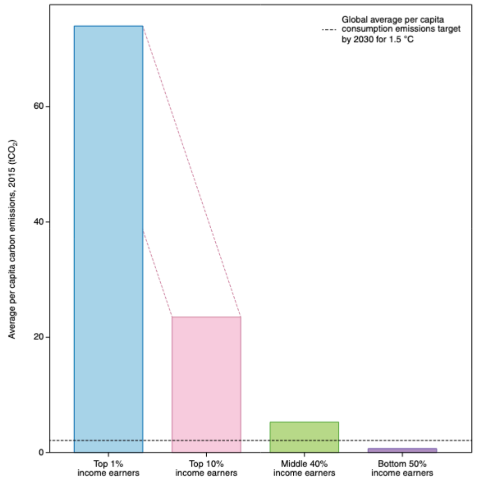

Fig. 1 | Who is responsible for carbon emissions world-wide? The richest 1% (income >US$109,000) of the population produce 15% of emissions and the 10% richest (>US$38,000) produce 48% of emissions. This shows that our lifestyle has the highest impact on our planet; wealthy people therefore have the highest imperative to change behaviour. Data taken from ref. [28].

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comment

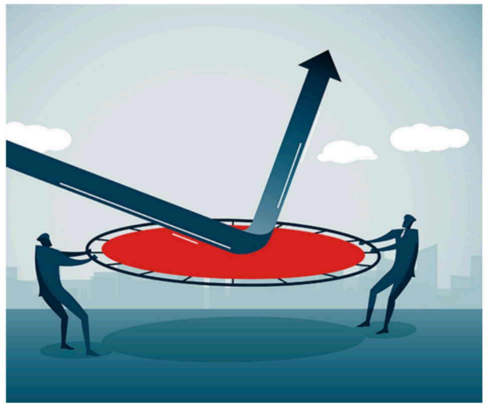
The need for political advocacy in astronomy

Astronomers are used to advocating for (financial) support for their future endeavours, but how should they go about lobbying for support for issues such as the climate emergency? Join forces with those experienced in effecting policy change.

Andrew Williams

In the modern era, astronomy seems far removed from politics, in part due to its focus on the discovery of fundamental knowledge and its universal truths, but also due to its relatively uncontentious findings and unobtrusive nature of observation. The areas in which astronomers do engage politically, or at least 'get political', generally concern advocating for funding, science policy issues affecting the field such as open access, conditions in academia or satellite constellations, and more recently, dealing with societal issues such as institutional racism, diversity and decolonization. Yet what should the astronomy community do for crises that transcend national politics or self-protection? The most pressing crisis of our time is the climate emergency, which will generate a range of drastic and negative societal impacts in a relatively short timescale unless governments and industries around the world take strong and concerted actions. The recently released report by the Intergovernmental Panel on Climate Change[1] (IPCC) further underscores the dire need for action.

The astronomy community has begun to grapple with reducing the climate impact of its own internal practices, from understanding the impact of professional conferences, to improving the environmental sustainability of observatories and computing facilities[2,3]. The recently formed Astronomers for Planet Earth group seeks to provide resources, support education about climate change and corral the community's efforts to reduce its overall carbon footprint. These internally focused actions are noteworthy for a relatively small scientific field representing a tiny sliver of global carbon output, yet what role can astronomers and the astronomy community play to address the key drivers of climate change and promote solutions? Should astronomers engage with politicians, governments and corporations, particularly in a domain already saturated with a huge range of interest groups and advocacy coalitions? There are two reasons why I think astronomers should engage.



Credit: Erhui1979 / DigitalVision Vectors / Getty

First, scientists are citizens and there is a moral imperative to engage given the dire consequences of inaction[4]. This imperative is even greater for scientists equipped with the capacity to understand the science and the impacts. As scientists, astronomers can immediately take action in a number of ways, from taking personal steps to reduce their carbon footprint, protesting, writing letters to politicians, government leaders and media, to addressing their own funding agencies and organizations. At an individual level, these uncoordinated actions are the bedrock of activism that keeps policy issues high on government agendas and on the radars of large corporations, yet astronomers can go further.

The second reason for engagement is that the astronomy community can add value to the climate policy domain through its unique perspective and authoritative and credible message. In addition to relatively unstructured and distributed activism, groups such as Astronomers for Planet Earth could take a coordinated approach to political advocacy.

This approach requires developing an appreciation for how policy change happens and understanding the system complexity in the climate policy domain. The 70-year-old discipline of policy science shows that policy change is mainly and often frustratingly incremental due the inertia associated with large systems, but with occasional 'punctuations' of rapid change. How this change happens depends hugely on the context, the nature of public opinion, political processes and timelines, the actions

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comment

Five steps for astronomers to communicate climate change effectively

Astronomers are trusted voices in the communication of science; our community should resist inundating people with facts and figures but use its advantage to encourage the public to listen to climate change experts and encourage the need for urgent cross-sectoral systemic change.

Alison Anderson and Gina Maffey

Climate change is one of the most serious challenges facing our planet and we are increasingly experiencing its dire effects with soaring temperatures, wildfires, floods and droughts. Within astronomy there is growing recognition of the urgency of the situation, the profession's impact on it and the need to communicate outside the academy[1–3]. Scientists are highly trusted by the public and tend to be seen as independent and non-controversial[4]. Astronomers are particularly well placed to communicate on climate change, given that the exciting nature of their subject often provides them with a platform in the media and the ability to reach out to very large numbers of people through a variety of public outreach events around the globe. Astronomy offers many entry points to talking about climate change, from the climate history of the terrestrial planets to the notion that there is no alternative planet for humans to live on: there is no 'Planet B'[3]. We argue that there is a real window of opportunity for astronomers to engage with the topic and weave climate change into their public engagement activities. There is a large body of research in science and environmental communication that can inform practice in the astronomy community and here we summarize the key findings.

Tell a story

Effective climate change communication requires two-way dialogue and strong narratives. Telling stories enables audiences to make sense of complex issues and human-interest narratives tend to be more memorable than numbers or graphs[5]. Best-practice guides on climate change communication recommend emphasizing scientific consensus while carefully explaining how a degree of uncertainty is present in all scientific work[6]. Metaphors can influence people's attitudes to climate change, while strong visual images and analogies should be relatable and, where possible, include people[7]. When crafting stories, however, it should be considered that the language and terminology used by scientists may not be shared by the public and can add to confusion about the issues[5,8]. As Somerville and Hassol point out: "Scientists typically fail to craft simple clear messages and repeat them often. They commonly overdo the level of detail, and people can have difficulty in sorting out what is important…Many words that

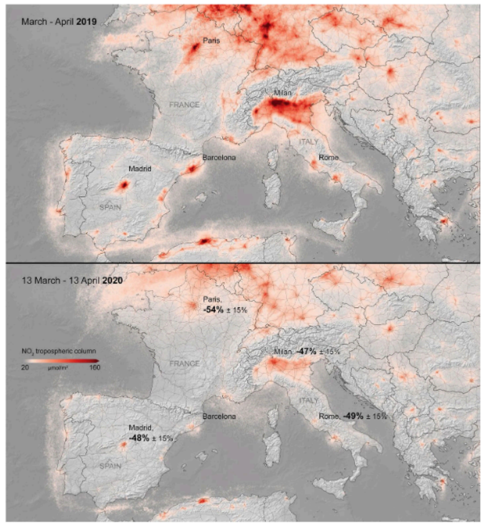
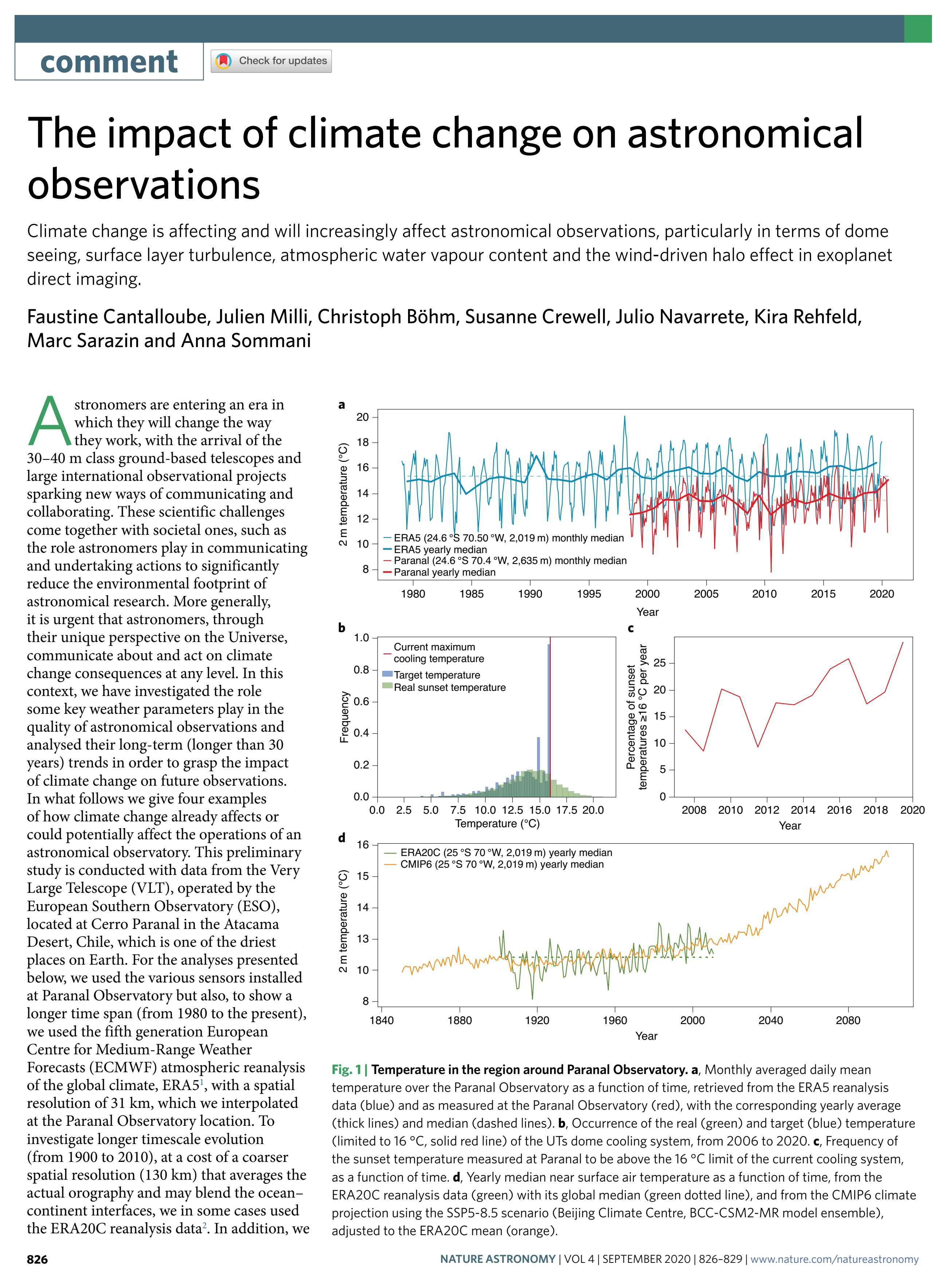


Fig. 1 | Nitrogen dioxide concentrations over Europe. These images use data from the Copernicus Sentinel-5P satellite to compare polluting nitrogen dioxide concentrations in March–April 2019 with the same period a year later, when pandemic restrictions were keeping many Europeans at home. Credit: Contains modified Copernicus Sentinel data (2019–20), processed by KNMI/ESA.



comment

Check for updates

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Climate change is affecting and will increasingly affect astronomical observations, particularly in terms of dome seeing, surface layer turbulence, atmospheric water vapour content and the wind-driven halo effect in exoplanet direct imaging.

Faustine Cantalloube, Julien Milli, Christoph Böhm, Susanne Crewell, Julio Navarrete, Kira Rehfeld, Marc Sarazin and Anna Sommani

Astronomers are entering an era in which they will change the way they work, with the arrival of the 30–40 m class ground-based telescopes and large international observational projects sparking new ways of communicating and collaborating. These scientific challenges come together with societal ones, such as the role astronomers play in communicating and undertaking actions to significantly reduce the environmental footprint of astronomical research. More generally, it is urgent that astronomers, through their unique perspective on the Universe, communicate about and act on climate change consequences at any level. In this context, we have investigated the role some key weather parameters play in the quality of astronomical observations and analysed their long-term (longer than 30 years) trends in order to grasp the impact of climate change on future observations. In what follows we give four examples of how climate change already affects or could potentially affect the operations of an astronomical observatory. This preliminary study is conducted with data from the Very Large Telescope (VLT), operated by the European Southern Observatory (ESO), located at Cerro Paranal in the Atacama Desert, Chile, which is one of the driest places on Earth. For the analyses presented below, we used the various sensors installed at Paranal Observatory but also, to show a longer time span (from 1980 to the present), we used the fifth generation European Centre for Medium-Range Weather Forecasts (ECMWF) atmospheric reanalysis of the global climate, ERA5[1], with a spatial resolution of 31 km, which we interpolated at the Paranal Observatory location. To investigate longer timescale evolution (from 1900 to 2010), at a cost of a coarser spatial resolution (130 km) that averages the actual orography and may blend the ocean–continent interfaces, we in some cases used the ERA20C reanalysis data[2]. In addition, we

Fig. 1 | Temperature in the region around Paranal Observatory. a, Monthly averaged daily mean temperature over the Paranal Observatory as a function of time, retrieved from the ERA5 reanalysis data (blue) and as measured at the Paranal Observatory (red), with the corresponding yearly average (thick lines) and median (dashed lines). **b**, Occurrence of the real (green) and target (blue) temperature (limited to 16 °C, solid red line) of the UTs dome cooling system, from 2006 to 2020. **c**, Frequency of the sunset temperature measured at Paranal to be above the 16 °C limit of the current cooling system, as a function of time. **d**, Yearly median near surface air temperature as a function of time, from the ERA20C reanalysis data (green) with its global median (green dotted line), and from the CMIP6 climate projection using the SSP5-8.5 scenario (Beijing Climate Centre, BCC-CSM2-MR model ensemble), adjusted to the ERA20C mean (orange).

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We witness the problem

We are part of the problem

We undergo the problem

Technology is indeed improving

BUT

we are also doing finer science

Paranal Observatory (Chile)

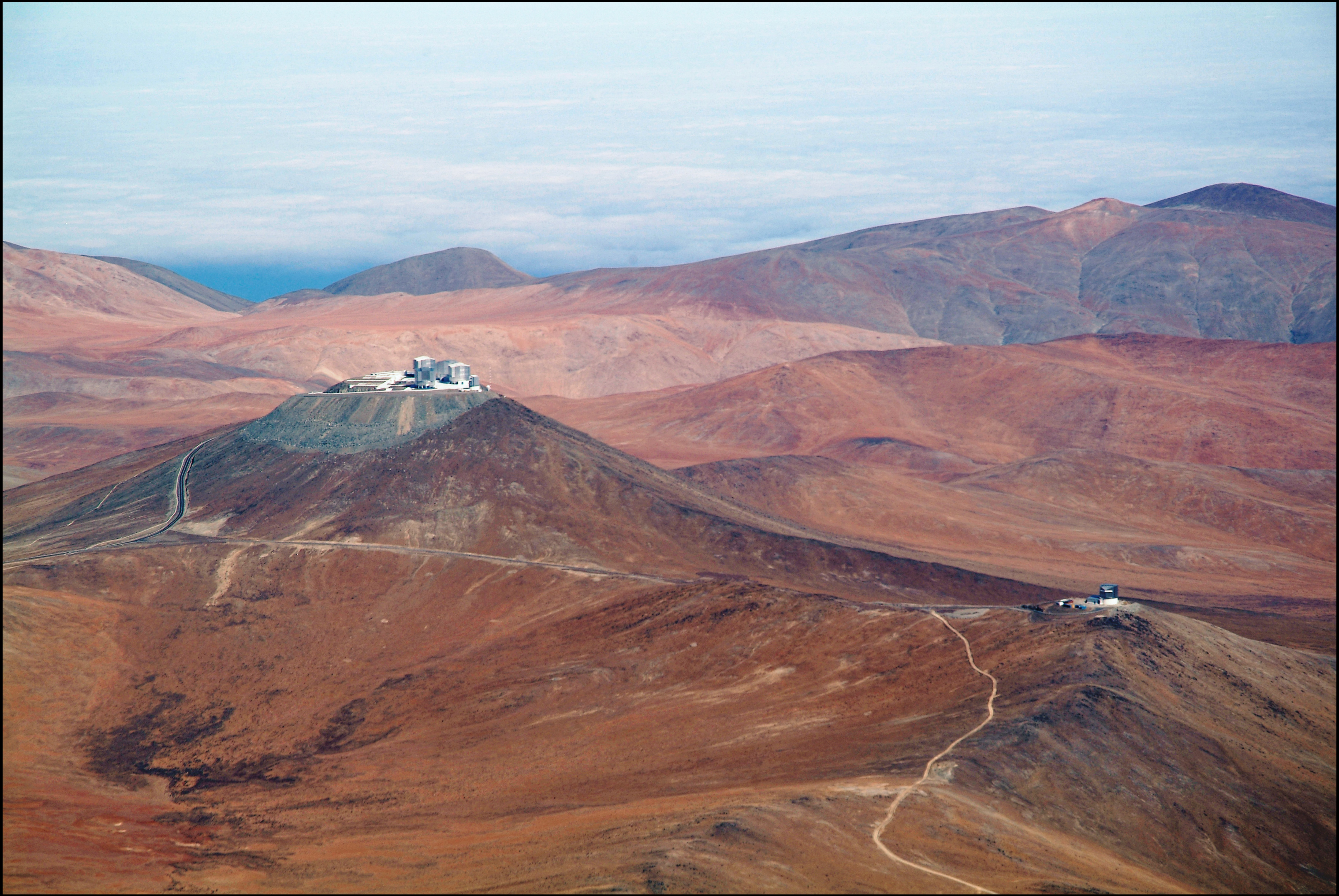
24°37′38″S 70°24′15″W

Very Large Telescope
(2635m)

©Google Earth

Paranal Observatory (Chile)

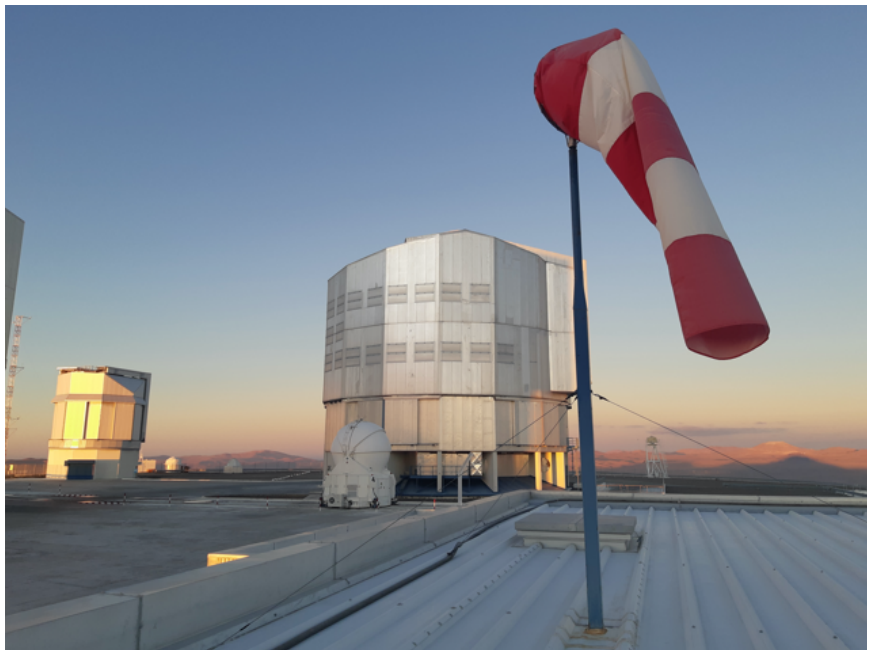
Paranal Observatory (Chile)



Paranal Observatory (Chile)

Data: -> suitable for climate studies !

- We collected ~30 years of ambiant meteorological data
- Re-analysis data are available (ECMWF, GMAO, NCEP/NCAR)
- Weather balloon (twice daily at Antofagasta)
- Projection for next century (IPCC-defined SSPs: CMIP)



Questions:

- Do we see the climate change in our observatory data ?
- How does it compare with external data ?
- Does it affect the quality of the observations ?
- What's gonna happen in ~20 years (ELT, SKA, ATC, AtLAST…)

Started in January 2020,
Collaboration with climatologists, meteorologists and atmosphere scientists

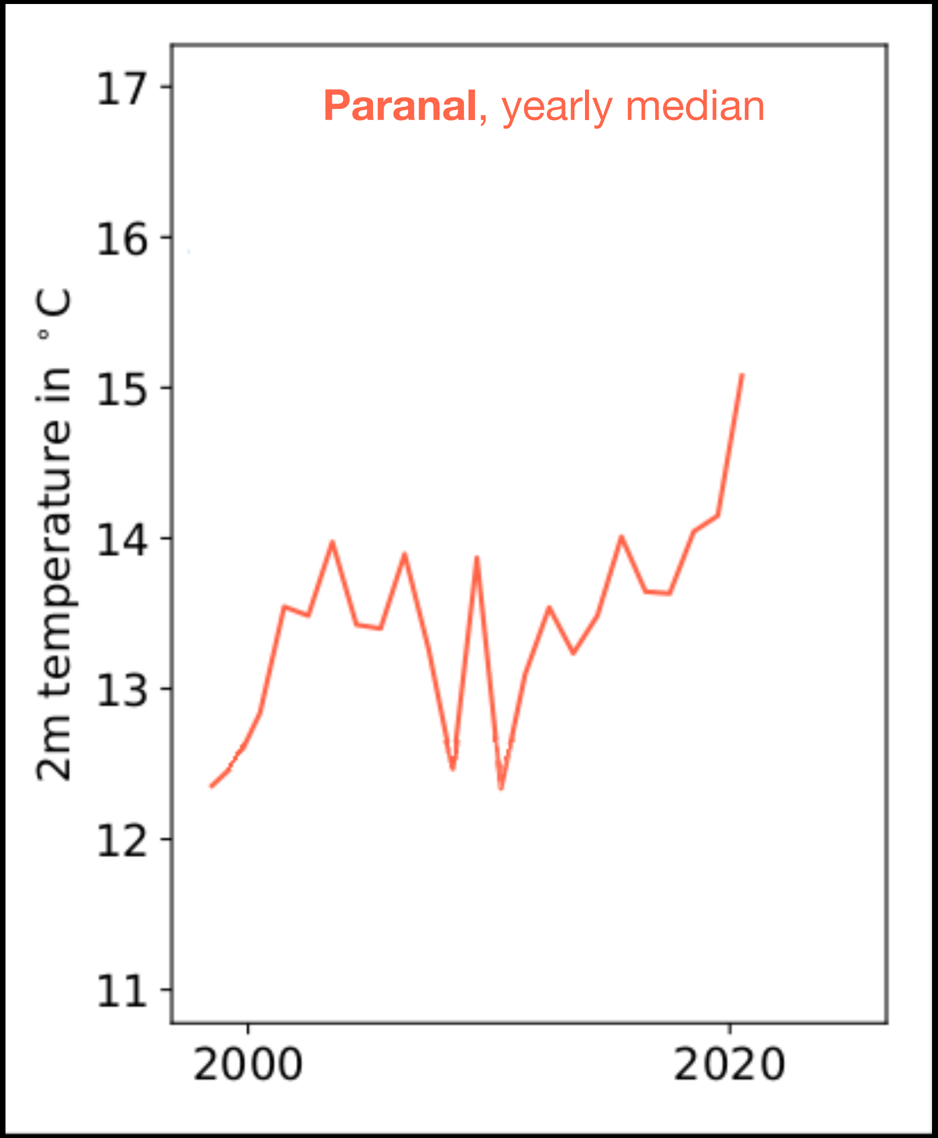
Four examples of climate change indicators

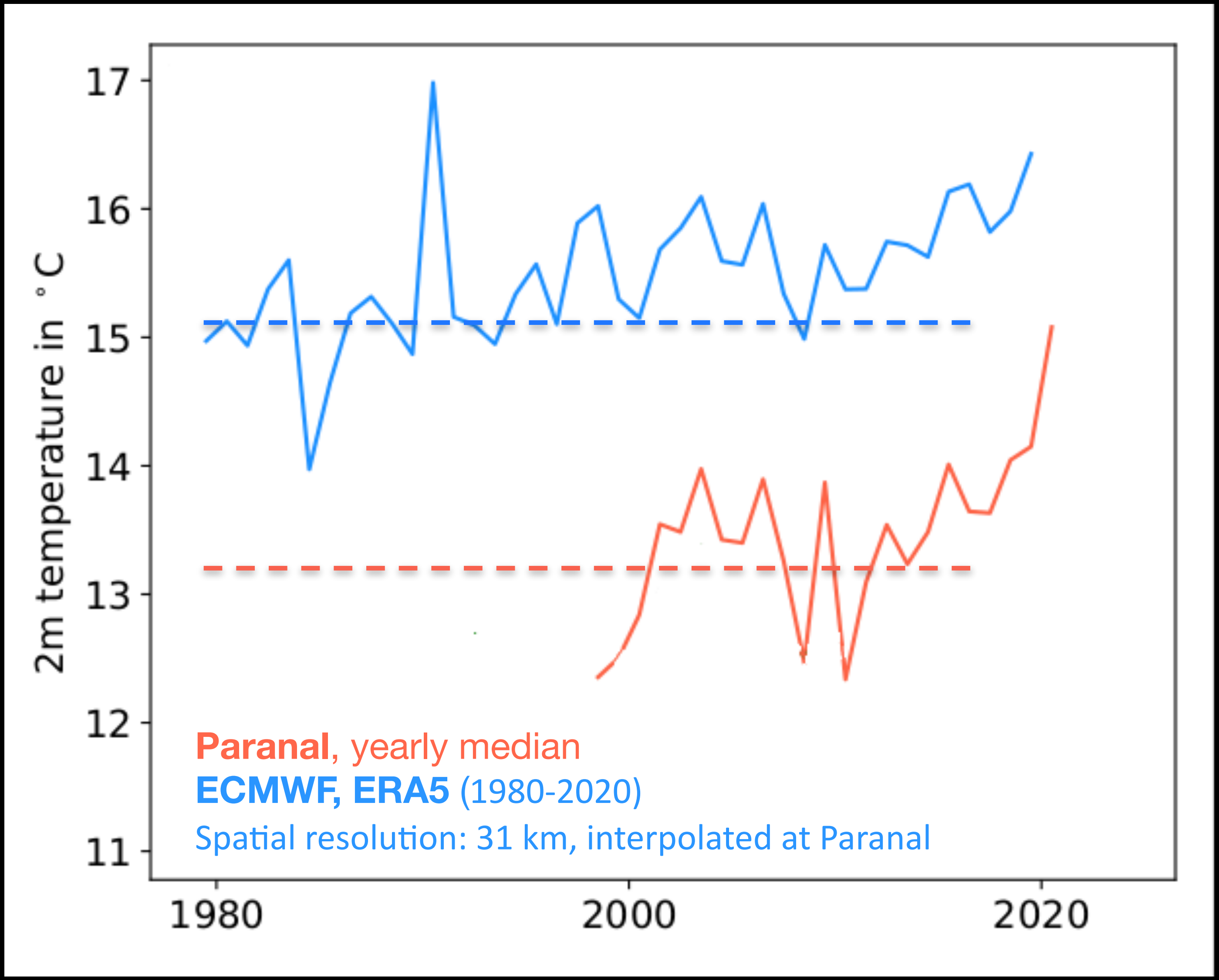
At Cerro Paranal observatory

MASS-DIMM (1998)

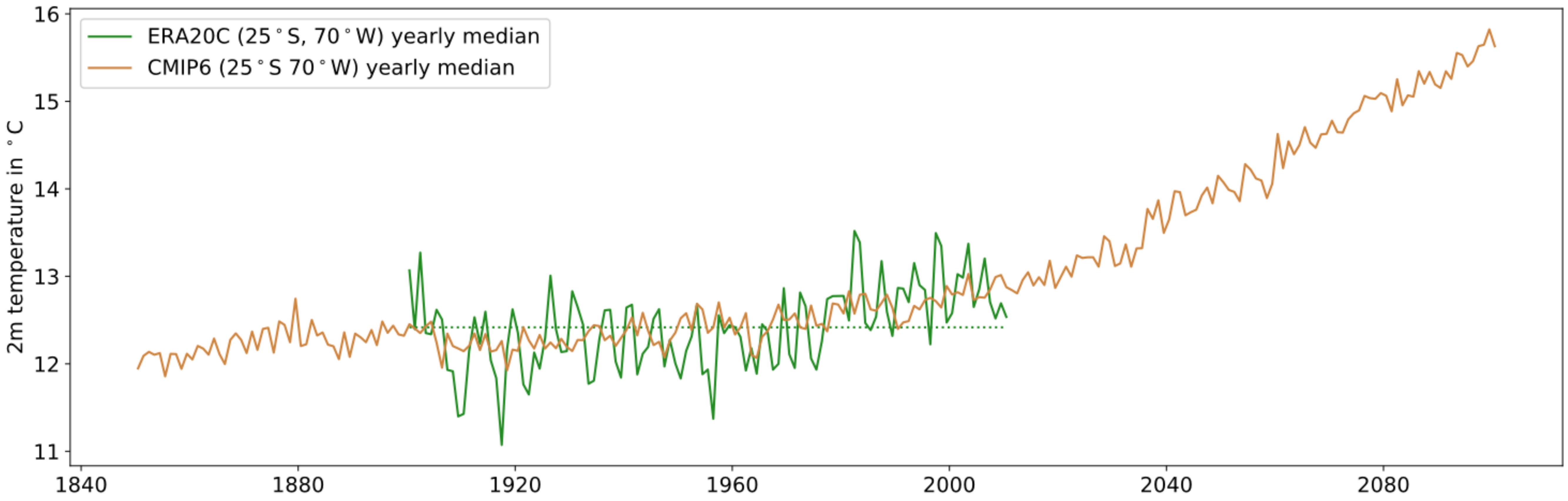
1. Temperature
2. Seeing
3. Jet stream wind speed
4. Humidity

1. Temperature: observations





1. Temperature: projection



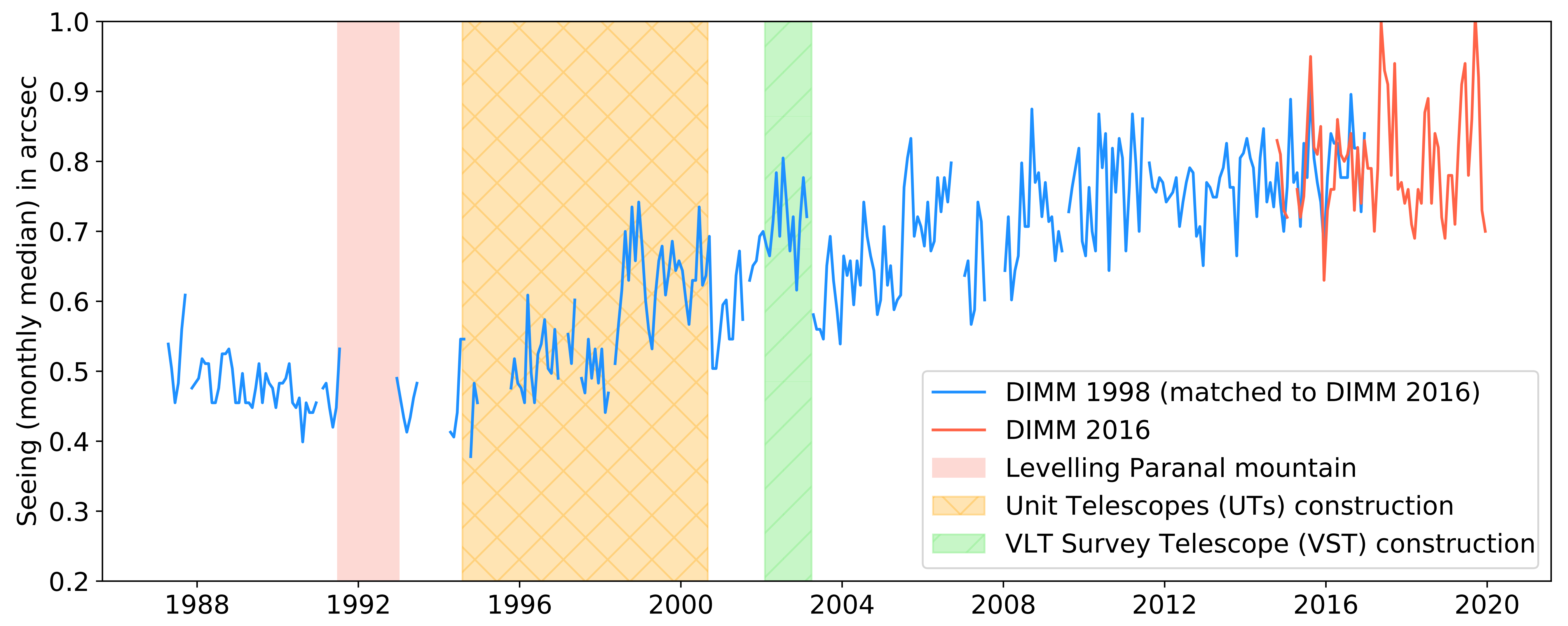
CMIP6

Climate projection using the SSP5-8.5 scenario
Beijing Climate Centre, BCC-CSM2-MR model ensemble

ECMWF

Reanalysis data ERA20C (1900-2010)
Spatial resolution: 130 km, ‘interpolated’ at Paranal

2. Surface Layer Seeing: observations



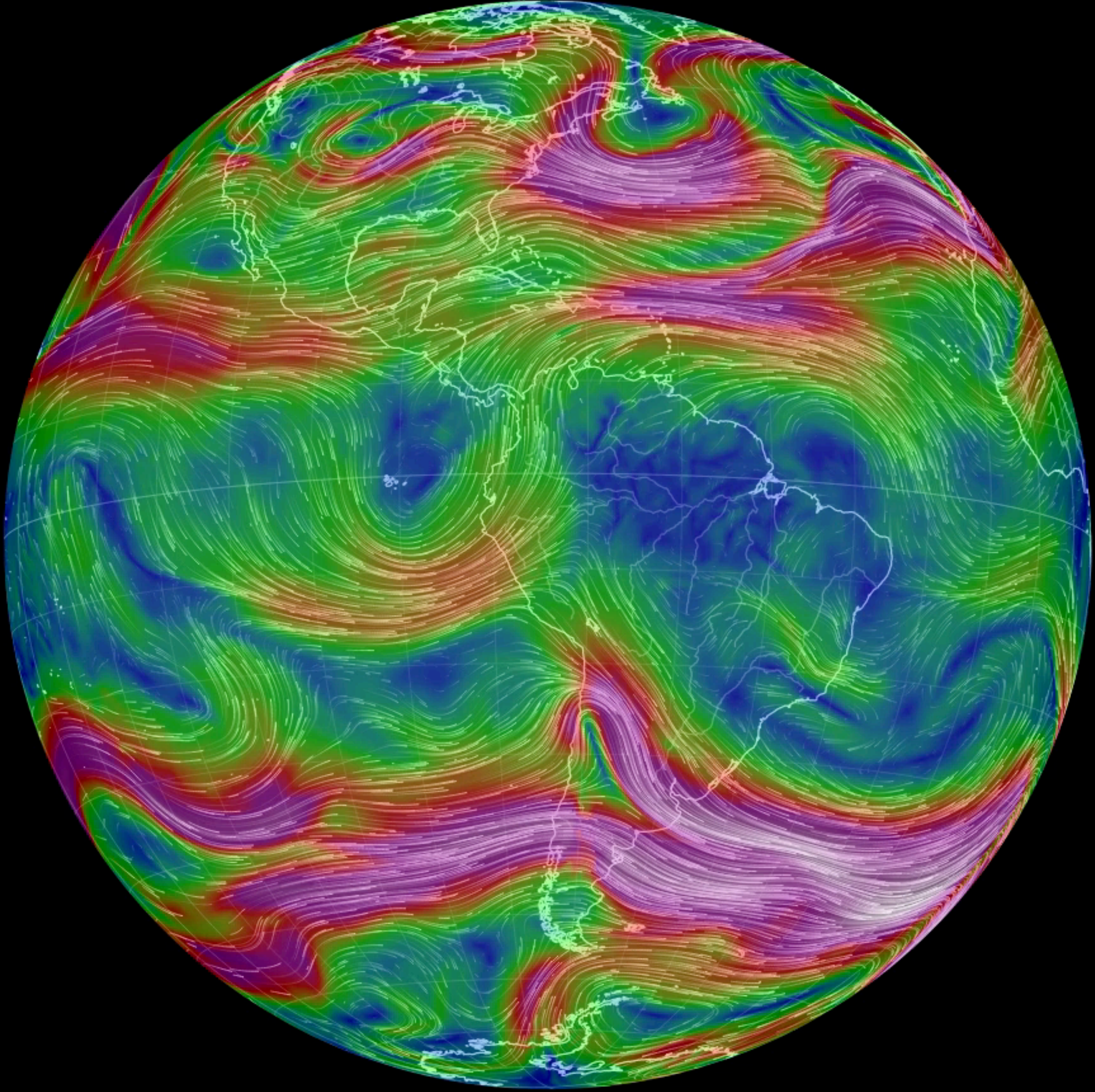
Two hypothesis:

(1) levelling of the mountain and the numerous changes of configuration of the DIMM

(2) the local changes due to global atmospheric circulation transition

Sarazin, M., Melnick, J., Navarrete, J. & Lombardi, G. Messenger 132, 11–17 (2008).

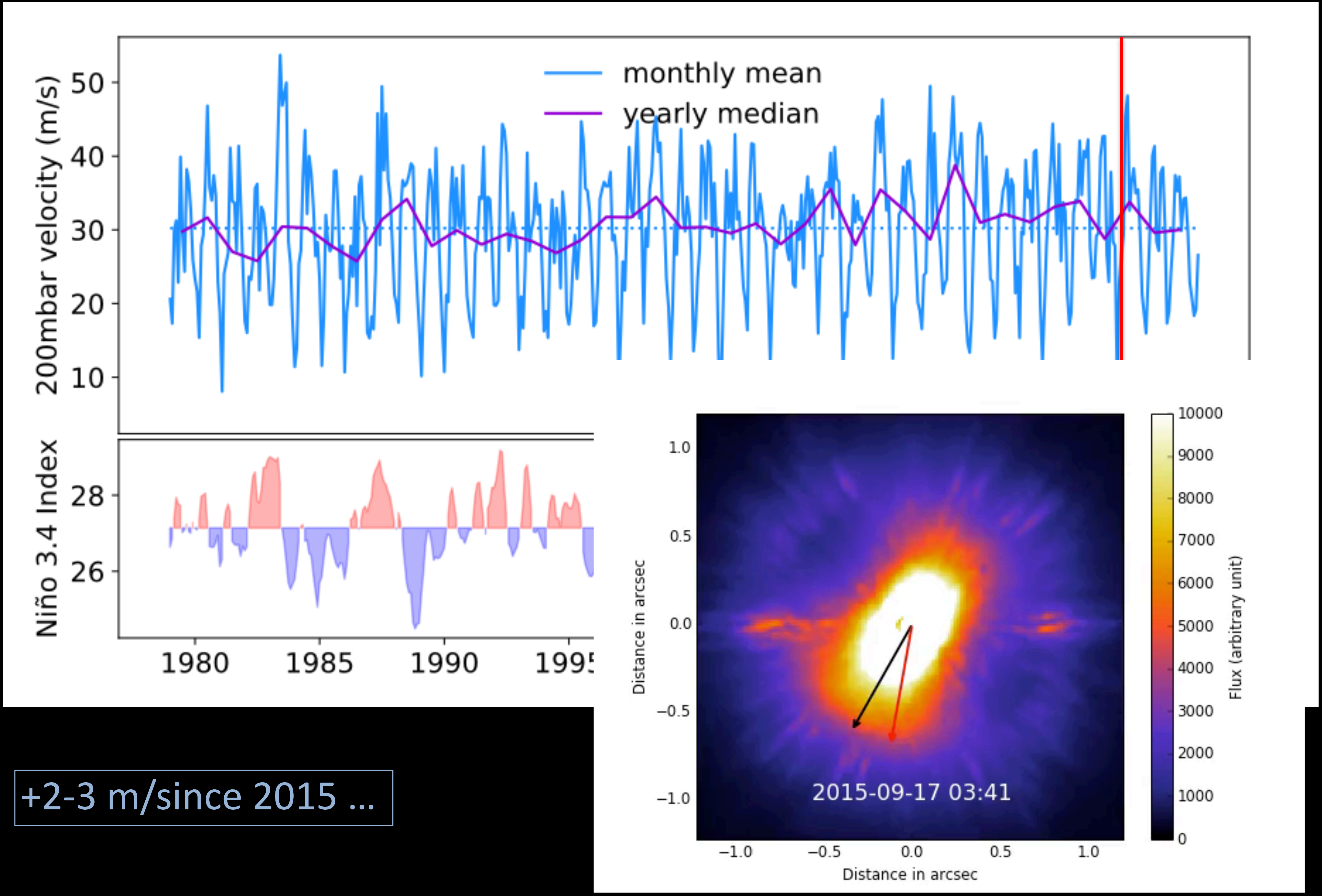
3. Jet stream wind-speed: definition



Subtropical **jet stream** layer: 12+/-1 km, 20 to 60m/s

https://earth.nullschool.net

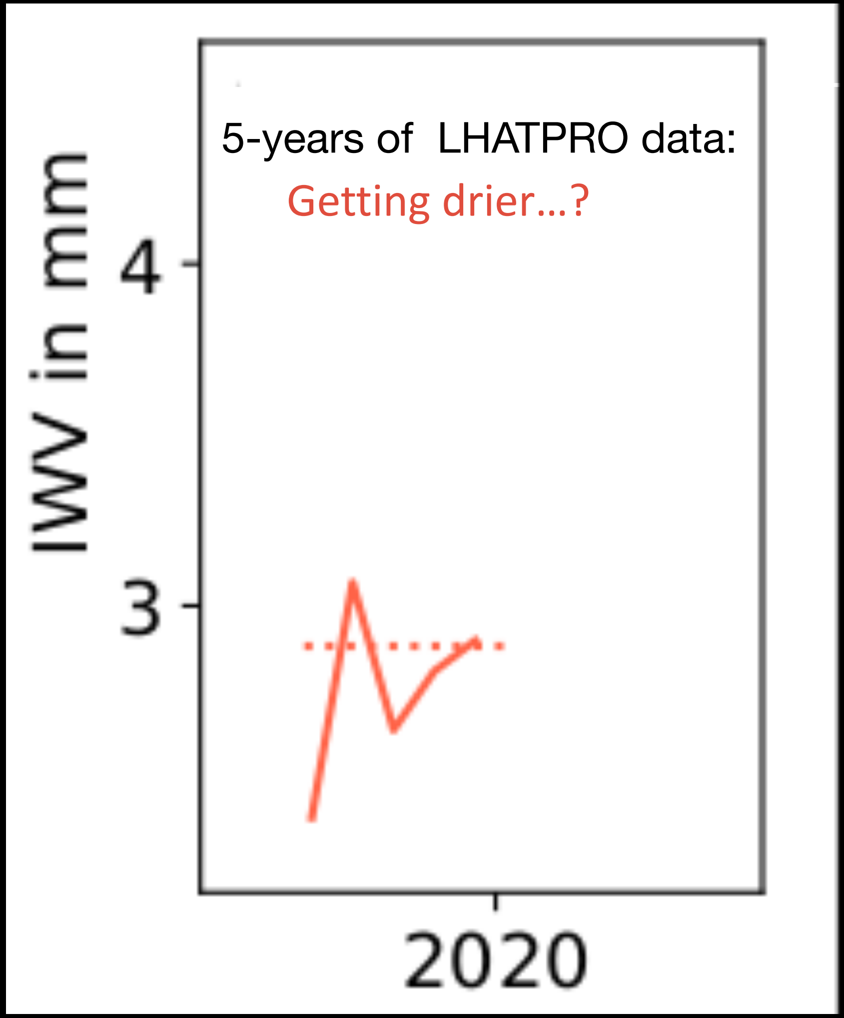
3. Jet stream wind-speed: observations



+2-3 m/since 2015 …

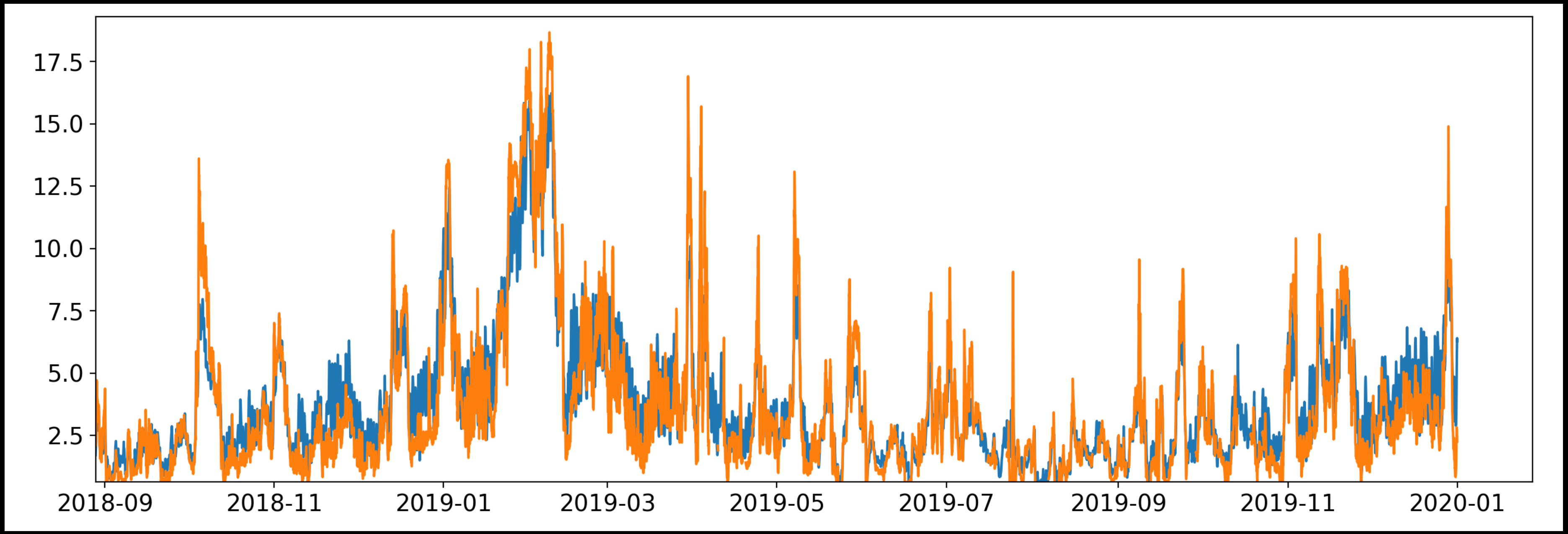
©J. Milli

4. Humidity: observations



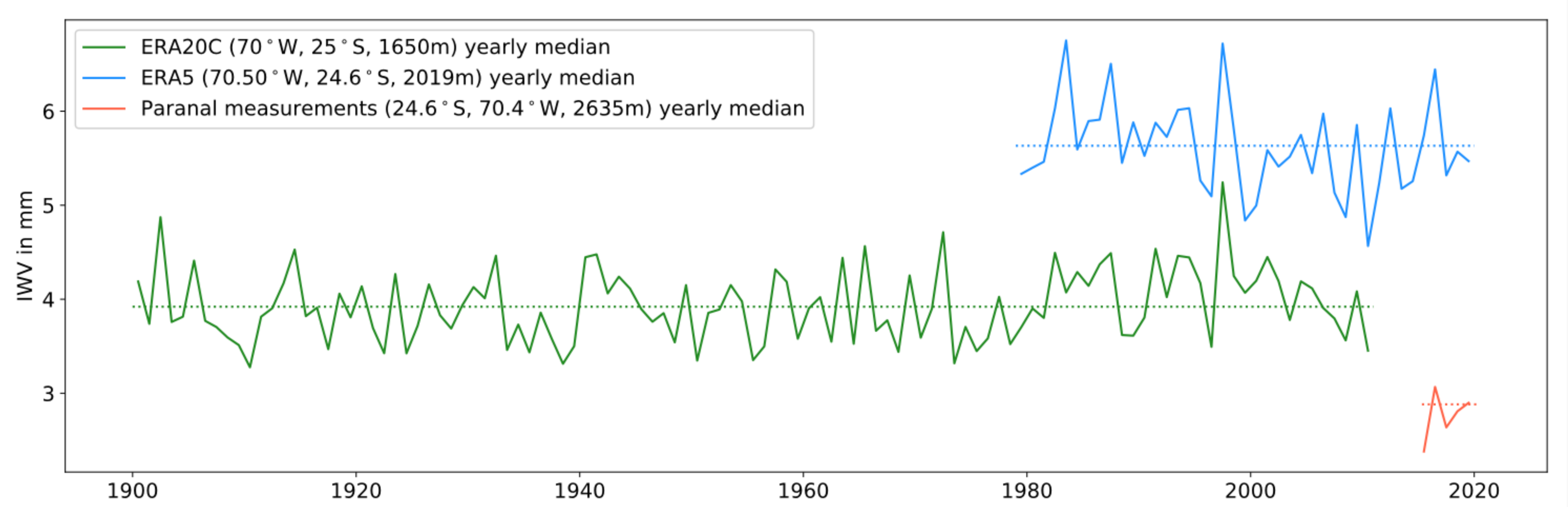
Low Humidity and Atmospheric Temperature PROfiling (LHATPRO)

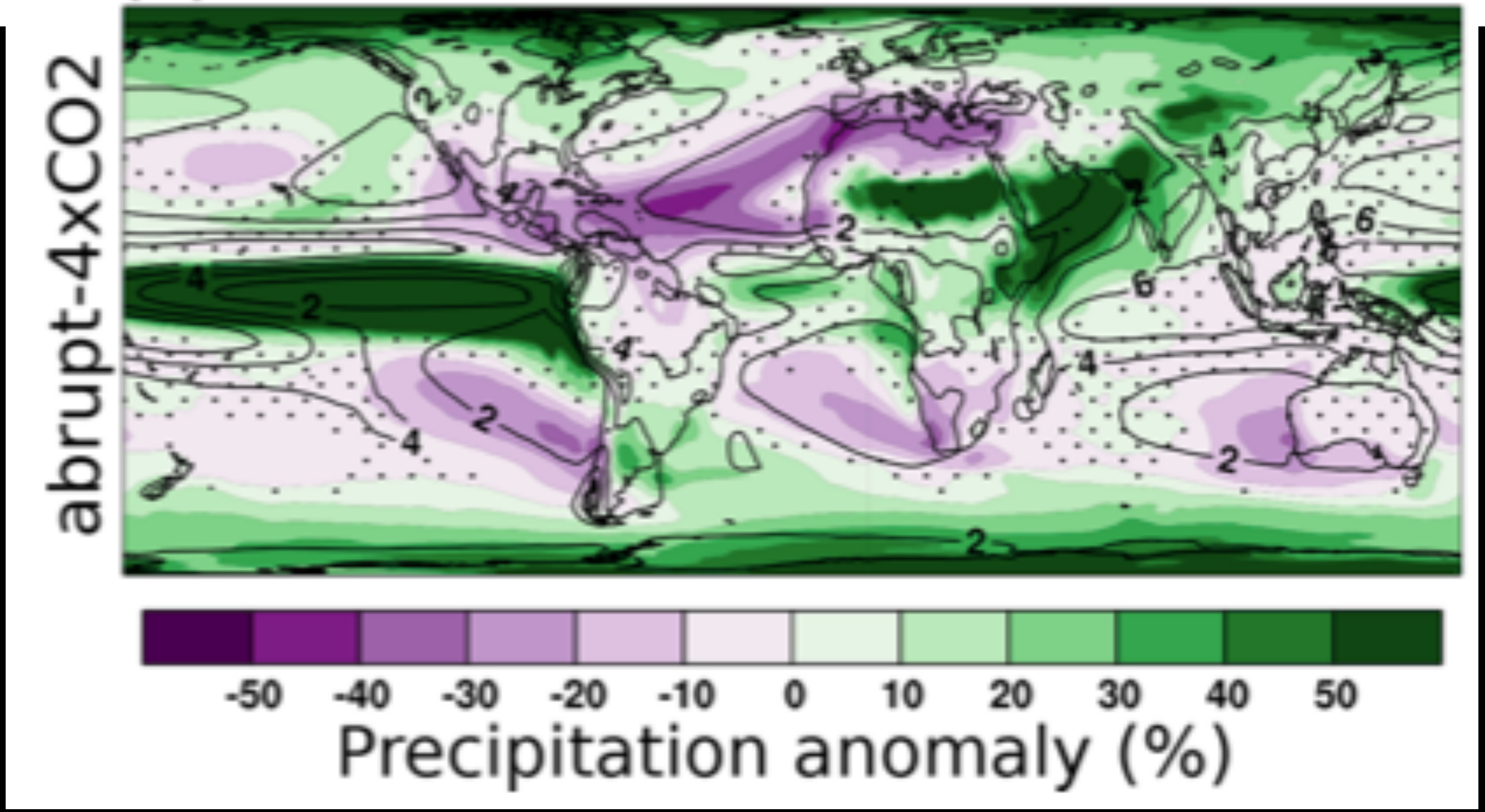
Kerber, F. et al. Proc. SPIE (2012)



Comparison ERA5-scaled vs LHATPRO

4. Humidity: observations & projections





Impact of climate change…

the elephant in the room

Mont Stromlo (2003)

© Australian Capital Territory Electricity and Water

Mont Graham (2006)

© Mount Graham International Observatory

Mont Wilson (2020)

© Mount Wilson Observatory

> *"In the future, under a warmer climate,*
> *we expect more severe fire weather, more area burned,*
> *more ignitions and a longer fire season."*

Flanningan et al., 2005,
Forest fires and climate change in the 21st century

Moritz et al., 2012
Climate change and disruptions to global fire activity

Impact of climate change...

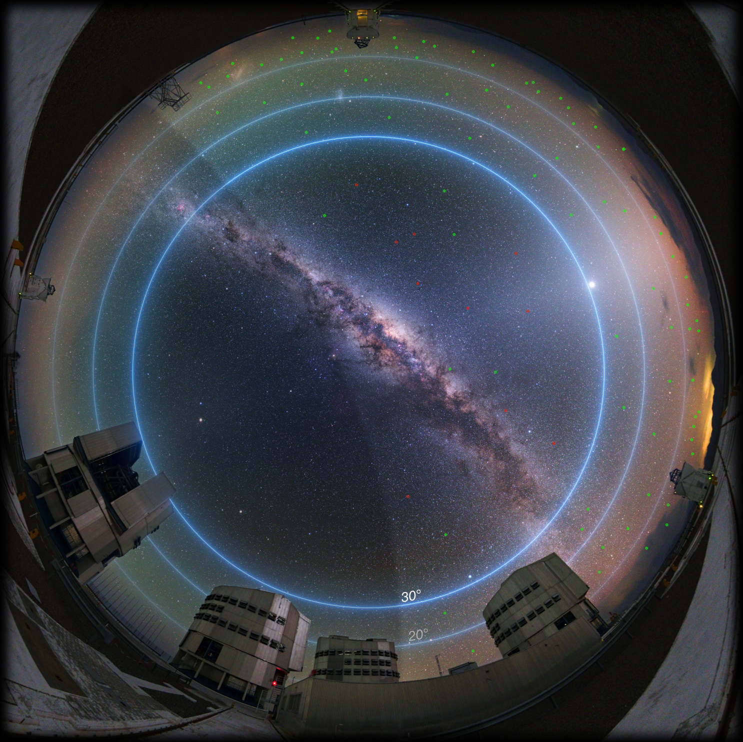
Ressources

Light pollution bottom-up

Local population

Commensality

Energy

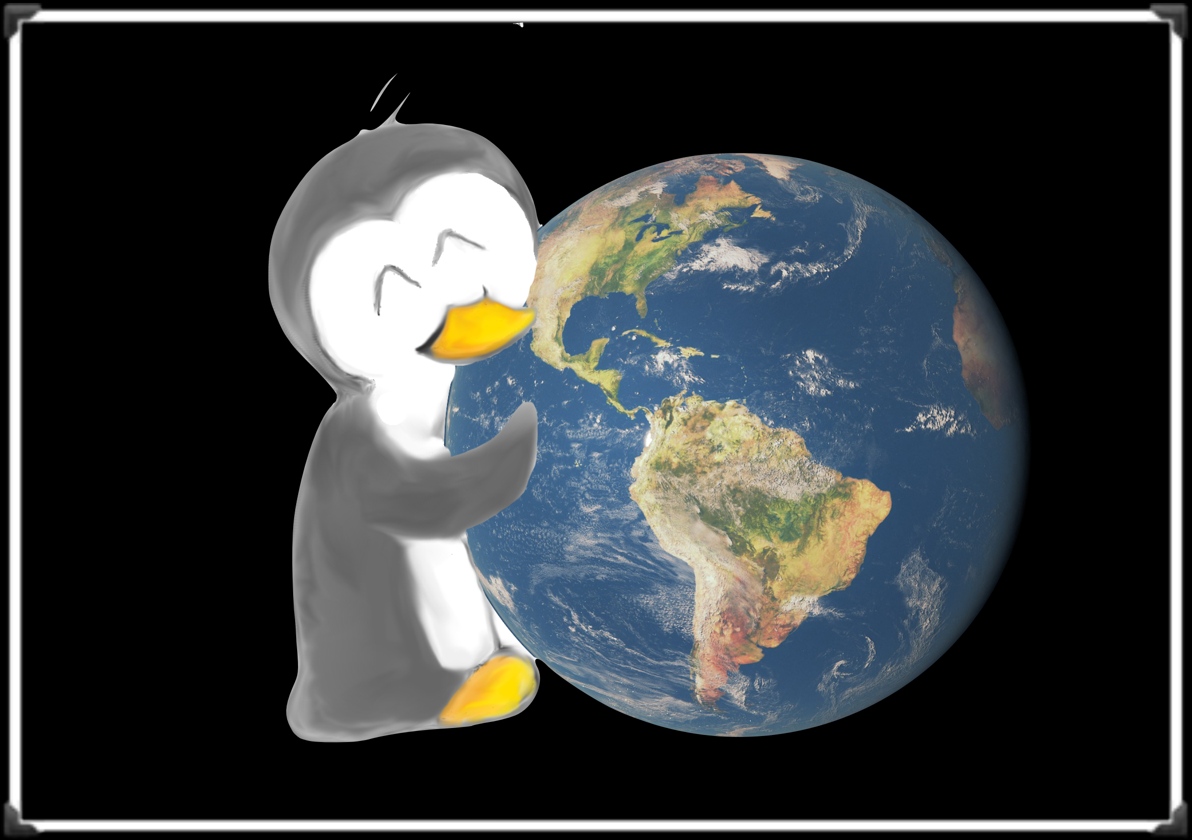


Light pollution top-down

Social stability is needed to run an observatory

Conclusions

- Yes, we see consequences of the anthropogenic global warming
- It starts to affect the quality of our observations
- Yet, it is difficult to firmly quantify / claim…
- And understand better large to small scale process !



Questions / comments / suggestions ?
Write me !
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Perspectives

- List the other obvious impact for future astronomical obs.
- Extend the current study to more parameters (VLT & ELT sites)
- Compare with more models / measurements / predictions
- Other man-made alterations (e.g. aerosols, light pollution…)
- … humidity …