

The background of the slide features a high-angle aerial photograph of the ocean. The water is a deep blue, with white and light blue patterns of ripples and waves. A prominent whitecap is visible in the lower right quadrant.

Marine Heatwaves in the Context of Compound Extremes

ICTP-CLIVAR Summer School 24-
24-29/07/2023

Regina R. Rodrigues
UFSC, Brazil



Compound Events

Motivation



Compound events **impact** human and natural systems



They are a combination of **multiple hazards** and/or drivers



Understanding the **physical processes** of compounding



Improving **predictability**, detection, attribution



Assessing societal and environmental impacts and **risks**



There are different **types** of compound events



Compound Events

Motivation

- ✓ Simultaneous multiple hazards
(Zscheischler et al. 2020)

2022: An abnormally hot summer with extreme weather events

Temperature anomalies
in July 2022*



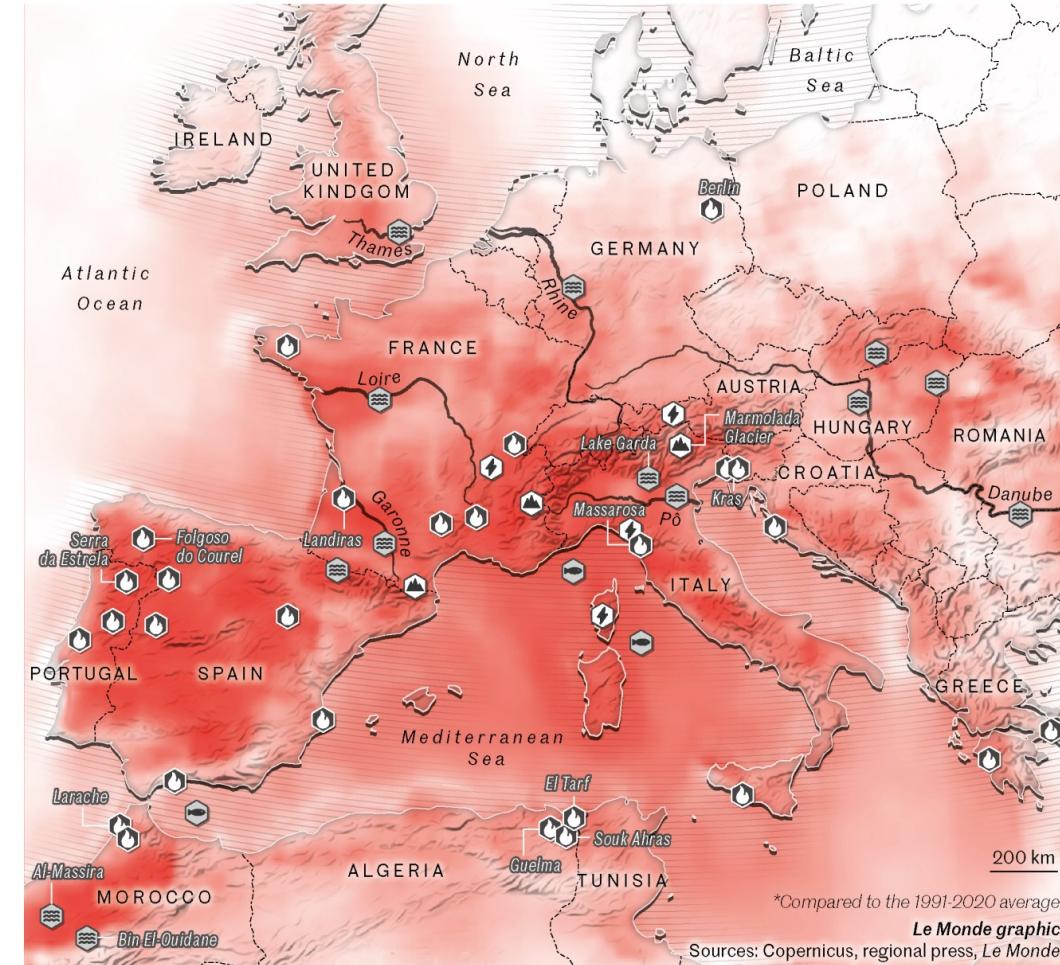
Major fires

Main dried-up rivers, lakes, and other water bodies

Violent rains and storms

Rockslides in mountains
and glacier collapses

Marine heatwaves





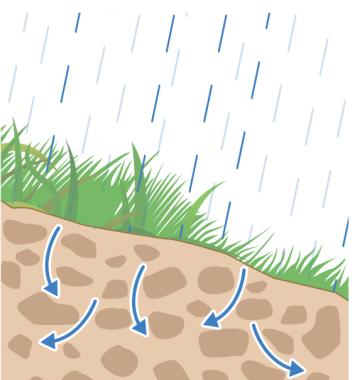
Compound Events

Motivation

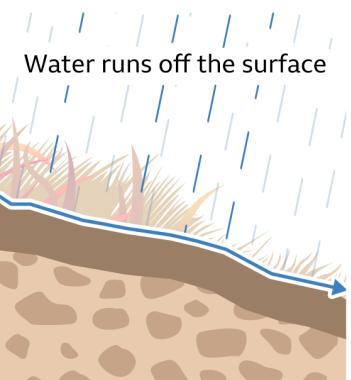
- ✓ Successive events
(Zscheischler et al. 2020)

Why flash floods happen after drought

Normal conditions

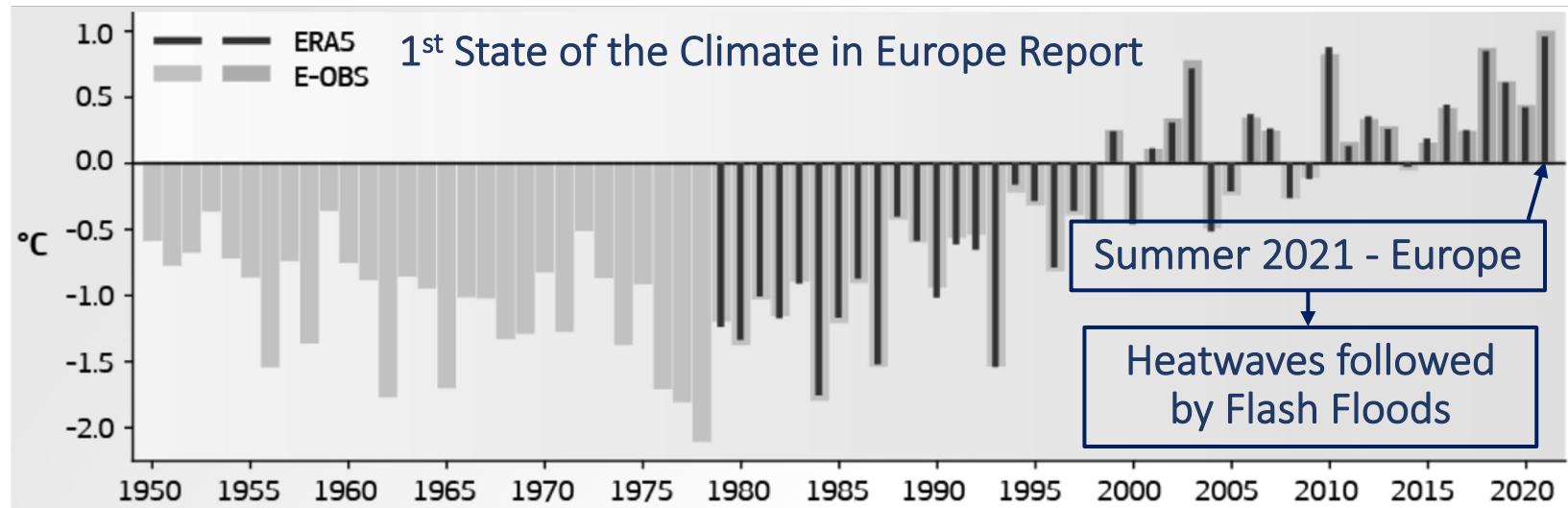


Drought conditions



Soil absorbs water like a sponge

Hard layer of soil repels water



Wet Grass

Normal Summer

After Heatwave



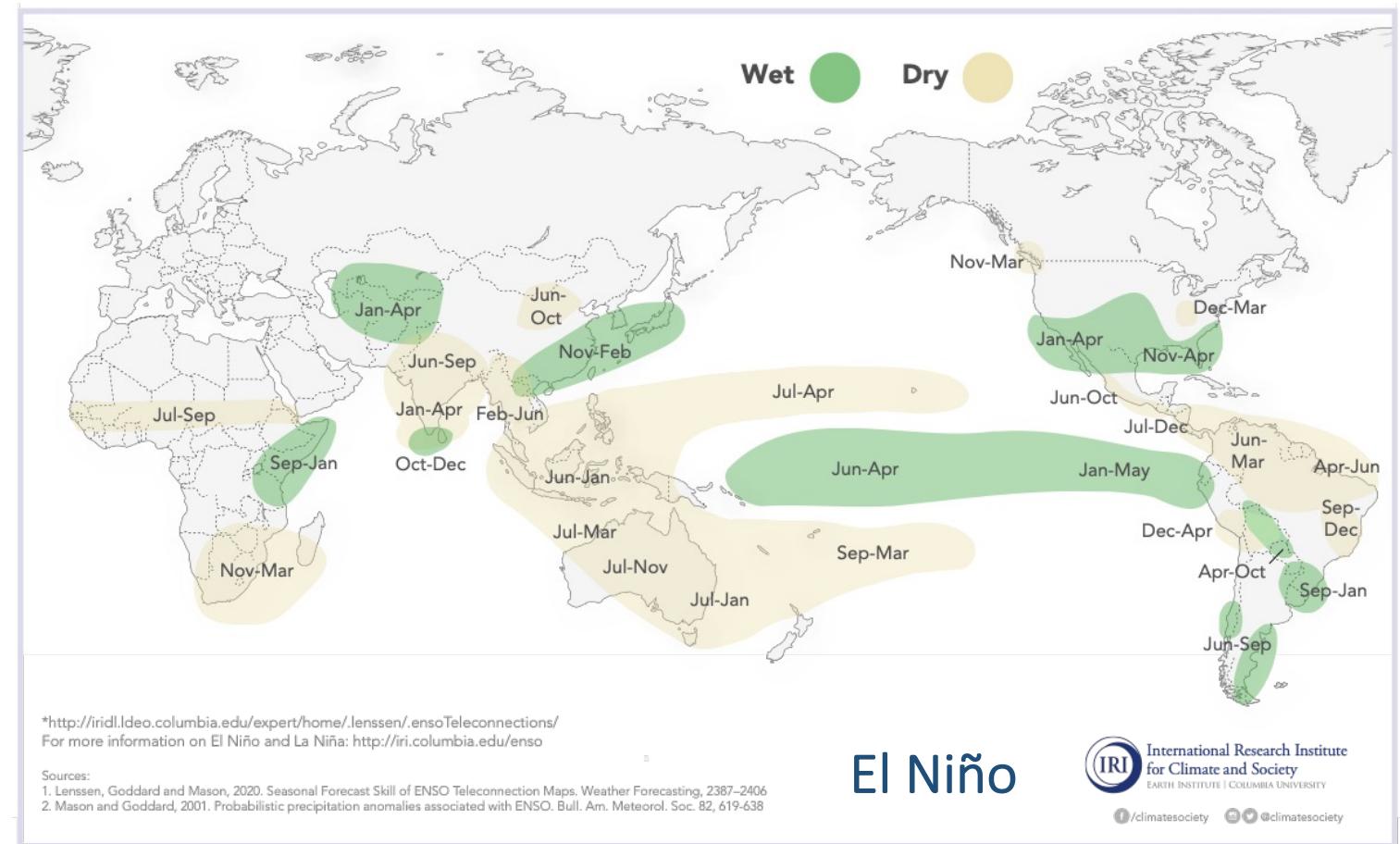
Compound Events

Motivation

- ✓ Spatially concurrent hazards - ENSO
(Zscheischler et al. 2020)

ENSO events causing droughts, heatwaves, floods

Global failure of breadbasket





Compound Events

Motivation

(Gruber et al. 2021; Burger et al. 2022)



Marine heatwaves are periods of extreme **ocean** temperatures



Marine heatwaves have different physical **drivers**



Marine heatwaves can cause devastating **impacts** on marine life



In many cases, marine heatwaves **co-occur** with other extremes



Extreme events on **land**, droughts, heatwaves, etc.



Extreme events in the **ocean**, of high acidity, low oxygen, etc.



Compound Events

Motivation

Land

Substantial

Land-Ocean

Limited

Ocean

Growing

nature reviews earth & environment

A typology of compound weather and climate events

Jakob Zscheischler , Olivia Martius, Seth Westra, Emanuele Bevacqua, Colin Raymond, Radley M. Horton, Bart van den Hurk, Amir AghaKouchak, Aglaé Jézéquel, Miguel D. Mahecha, Douglas Maraun,

nature geoscience

Common cause for severe droughts in South America and marine heatwaves in the South Atlantic

Regina R. Rodrigues , Andréa S. Taschetto, Alex Sen Gupta & Gregory R. Foltz

nature

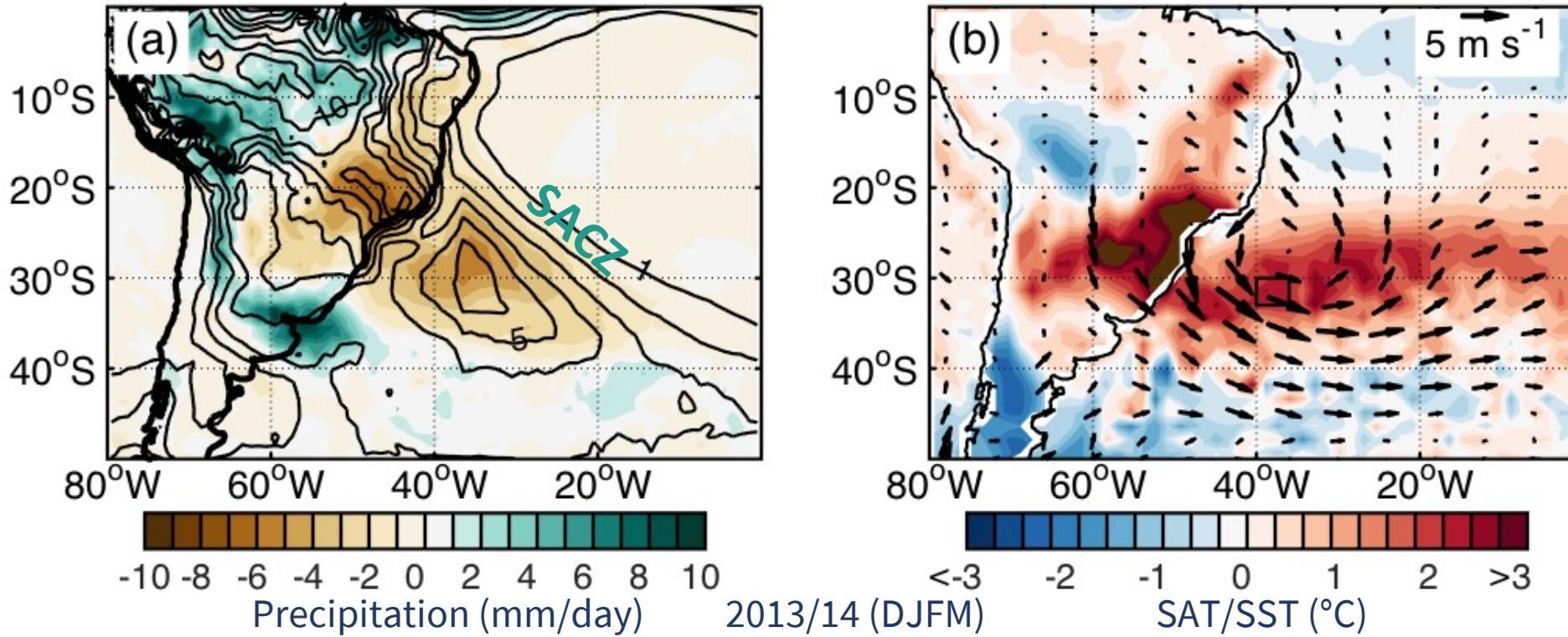
Biogeochemical extremes and compound events in the ocean

Nicolas Gruber , Philip W. Boyd, Thomas L. Frölicher & Meike Vogt



Compound Events

Land-Ocean Compound

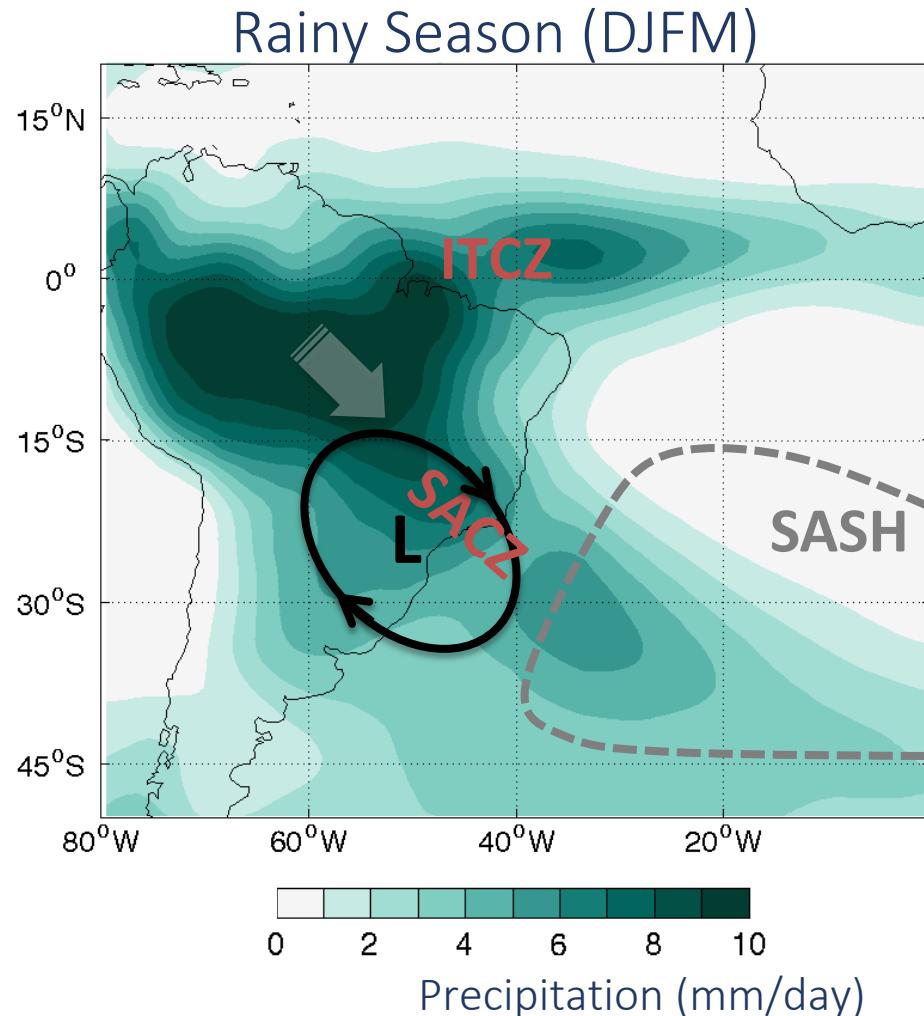


✓ Marine heatwaves are associated with droughts and land heatwaves → Compound extreme events



Compound Events

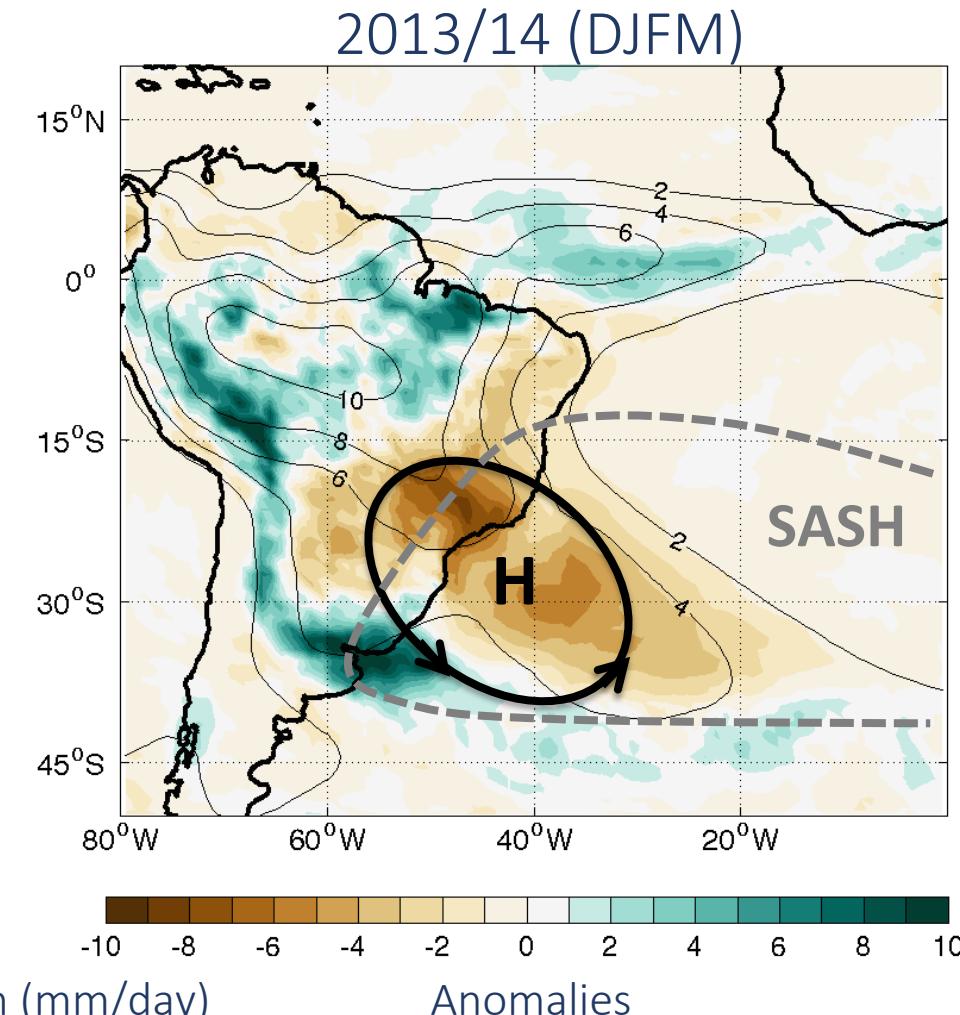
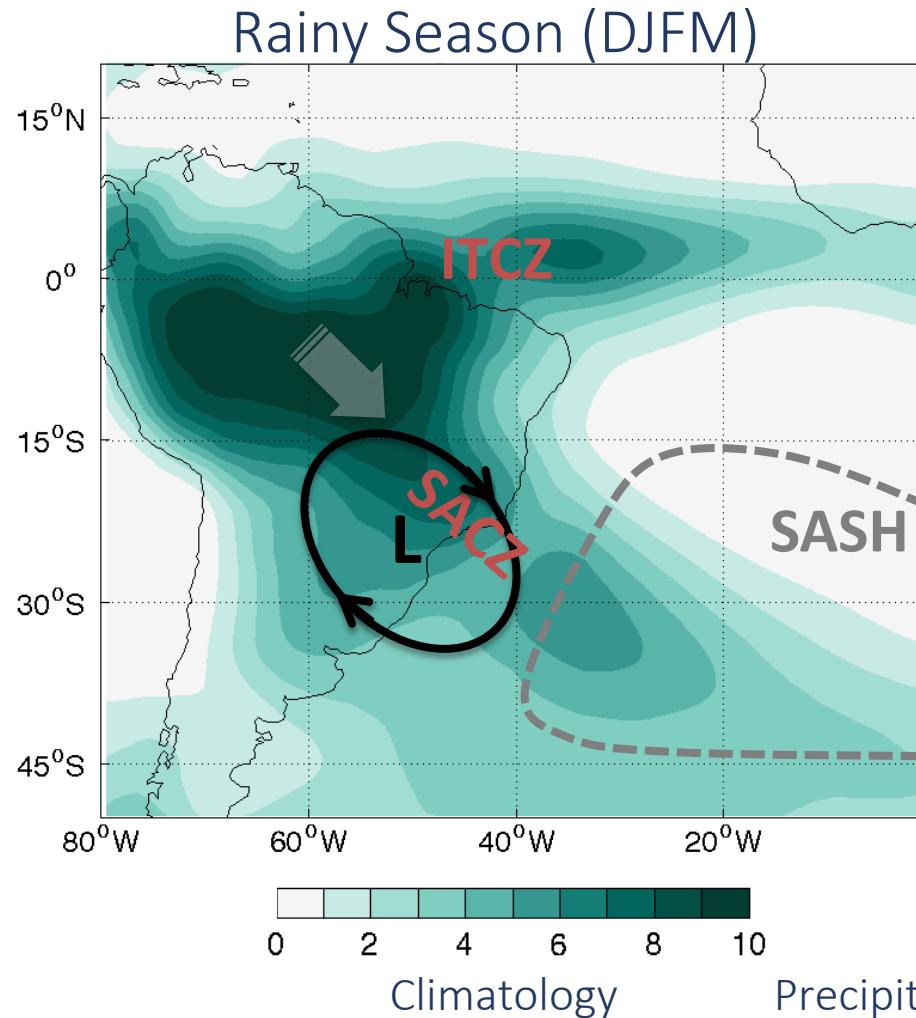
Land-Ocean Compound





Compound Events

Land-Ocean Compound

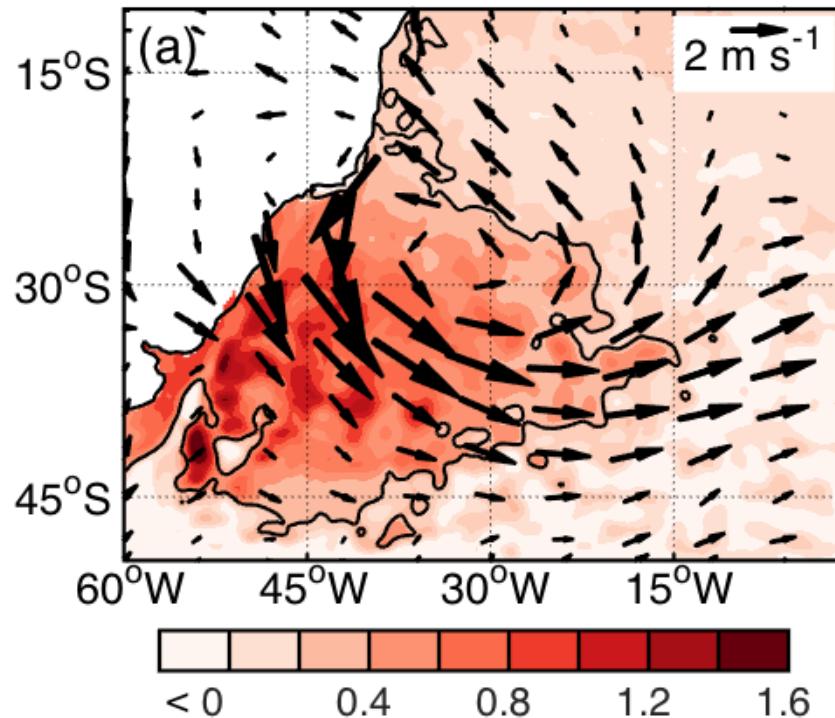




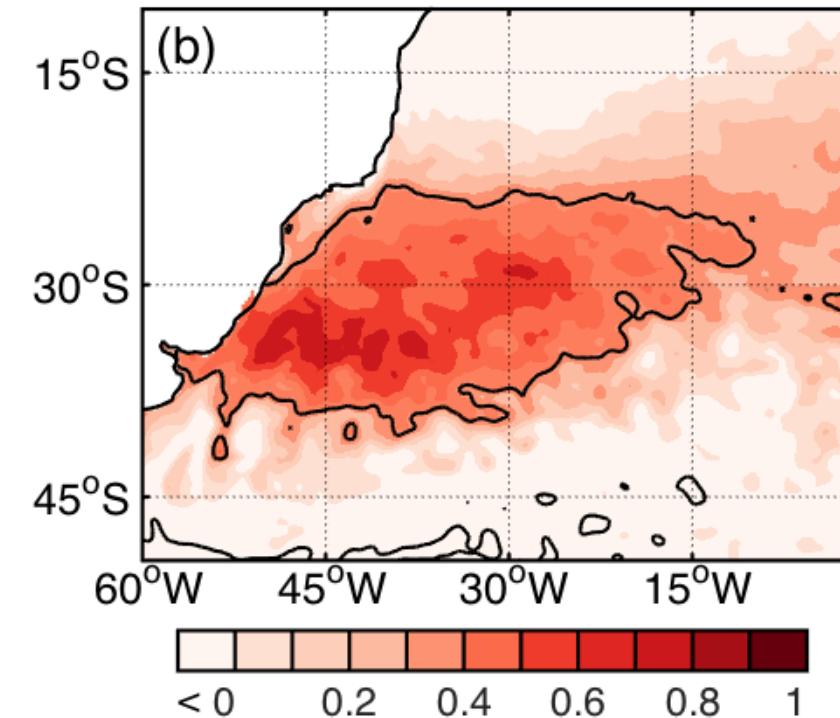
Compound Events

Land-Ocean Compound

Composites SST+WIND all MHWs



Correlation SST - Blocking

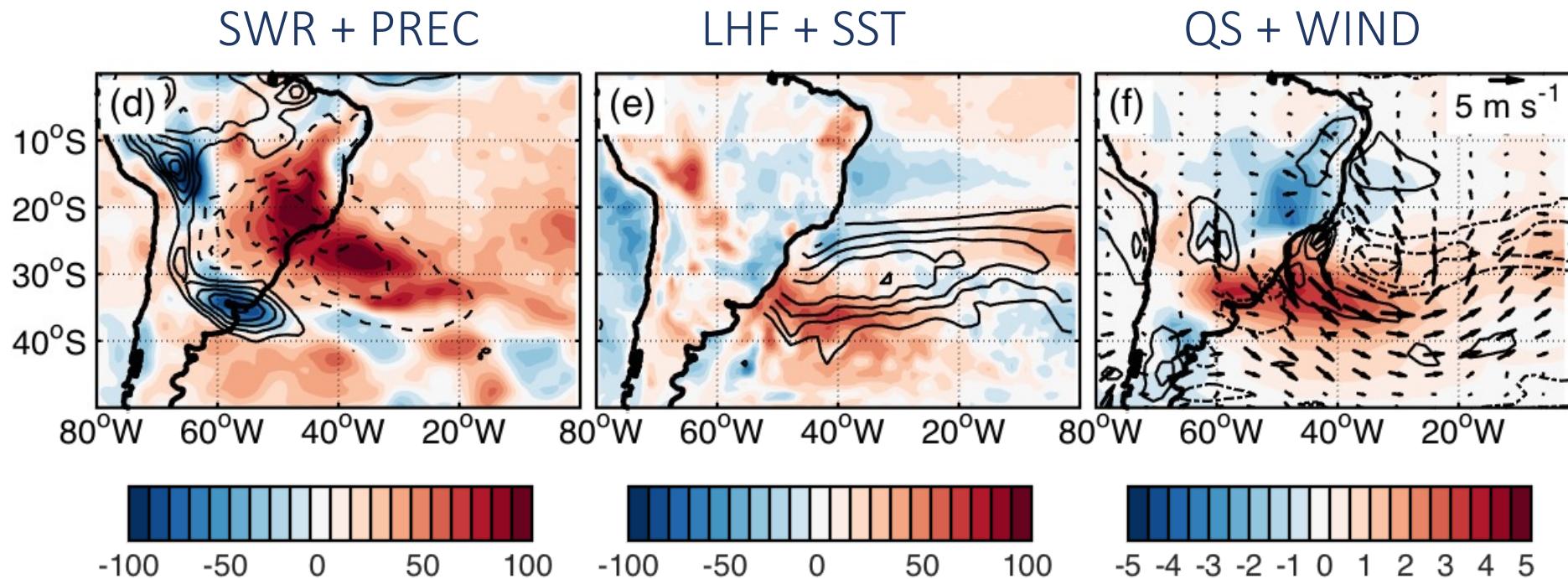


✓ Up to 60% of MHW days occur simultaneously with atmospheric blocking days (1982-2016)



Compound Events

Land-Ocean Compound

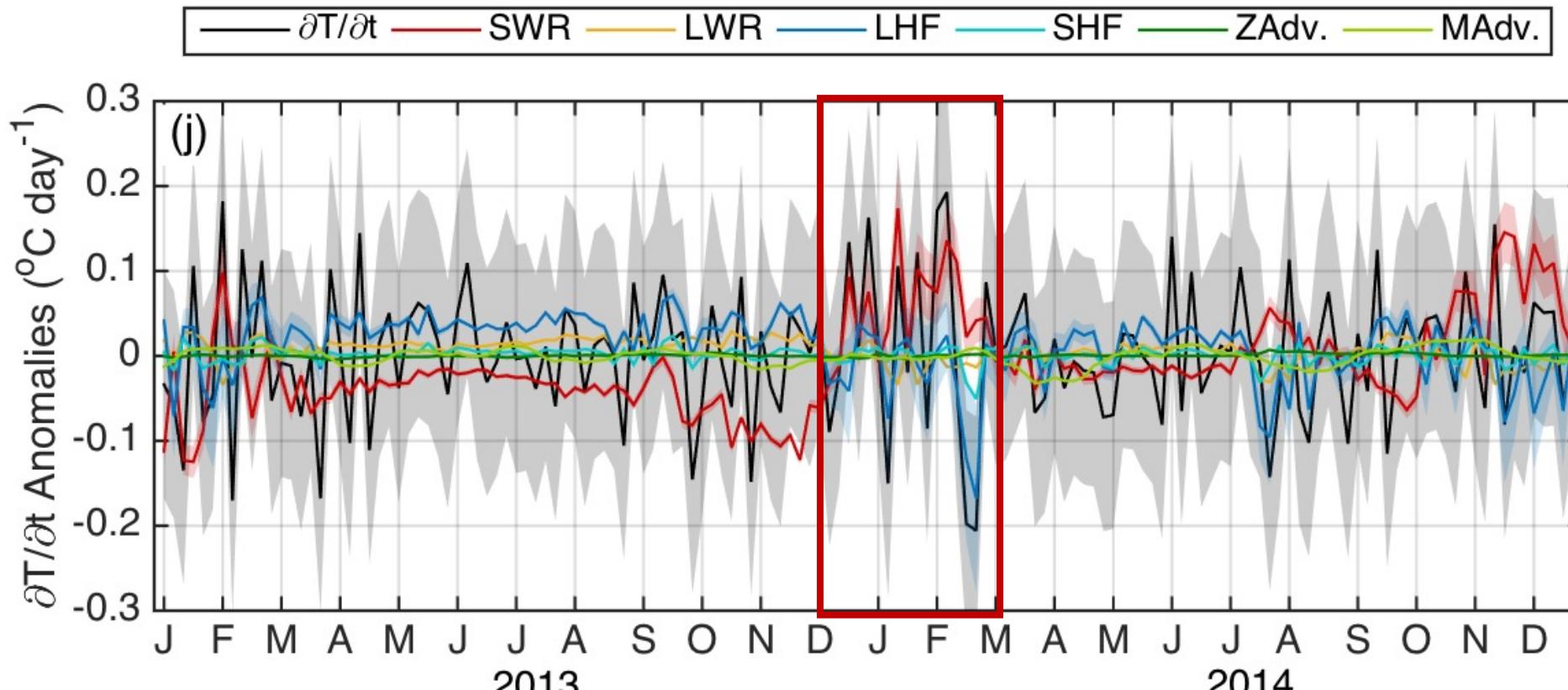


Surface heat fluxes during the 2013/14 Event



Compound Events

Land-Ocean Compound

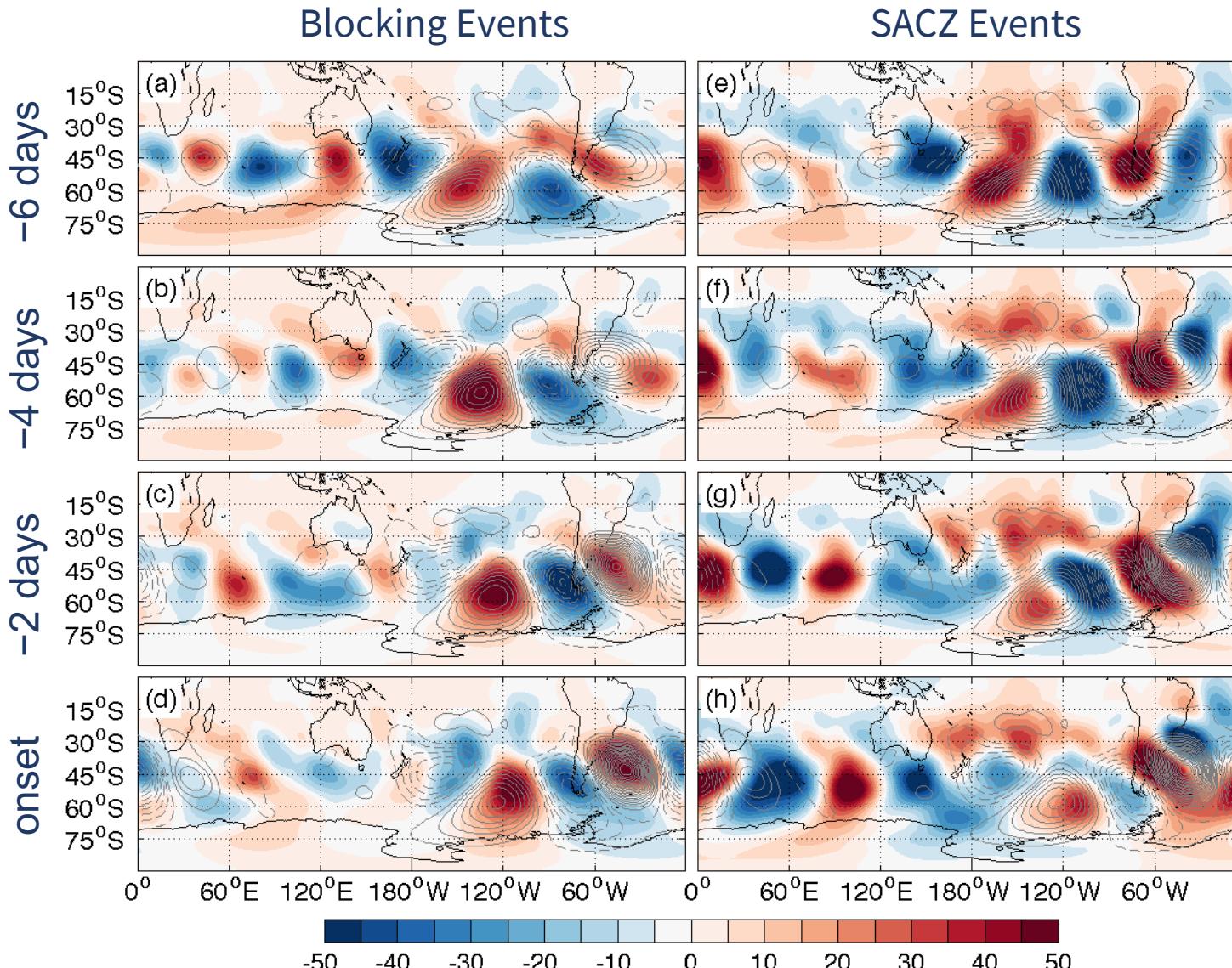


Mixed-Layer Temperature Budget ($30^{\circ}\text{S}-33^{\circ}\text{S}$, $36^{\circ}\text{W}-40^{\circ}\text{W}$)

$$\partial T / \partial t = -v \cdot \nabla T + Q_o / \rho C_p h + \epsilon$$



Compound Events

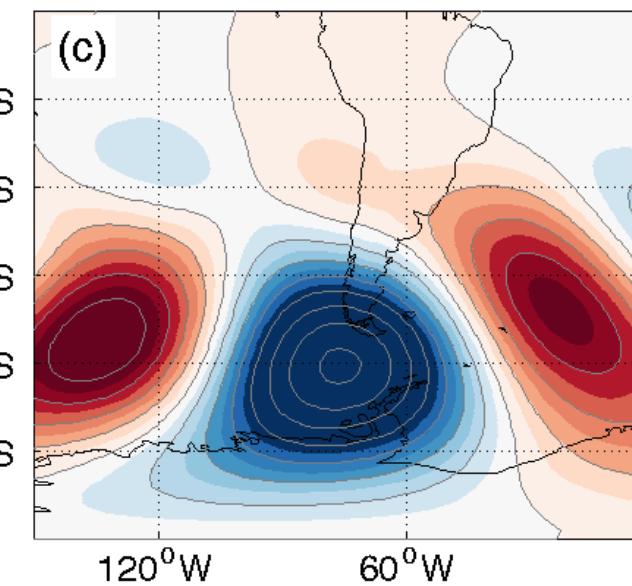
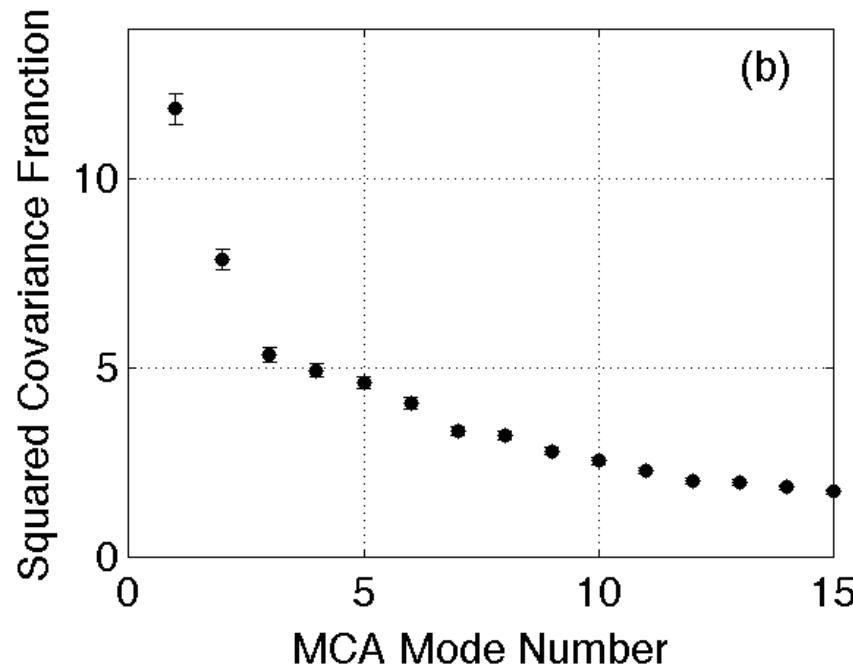
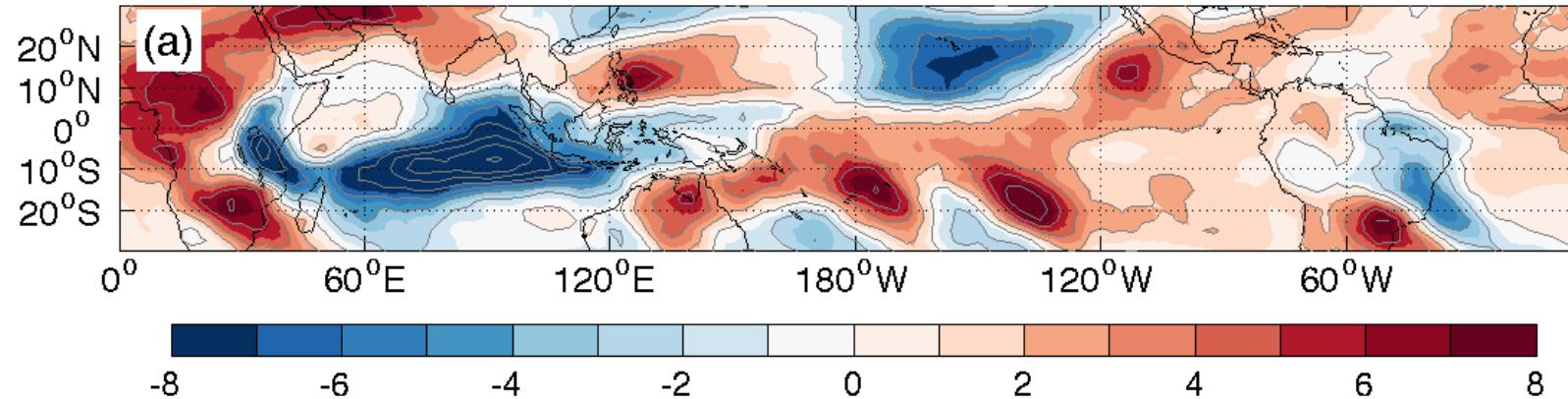


Composites of Z200hPa for all MHW (1979-2016)

Rodrigues & Woollings (2017, JCLIM)



Compound Events



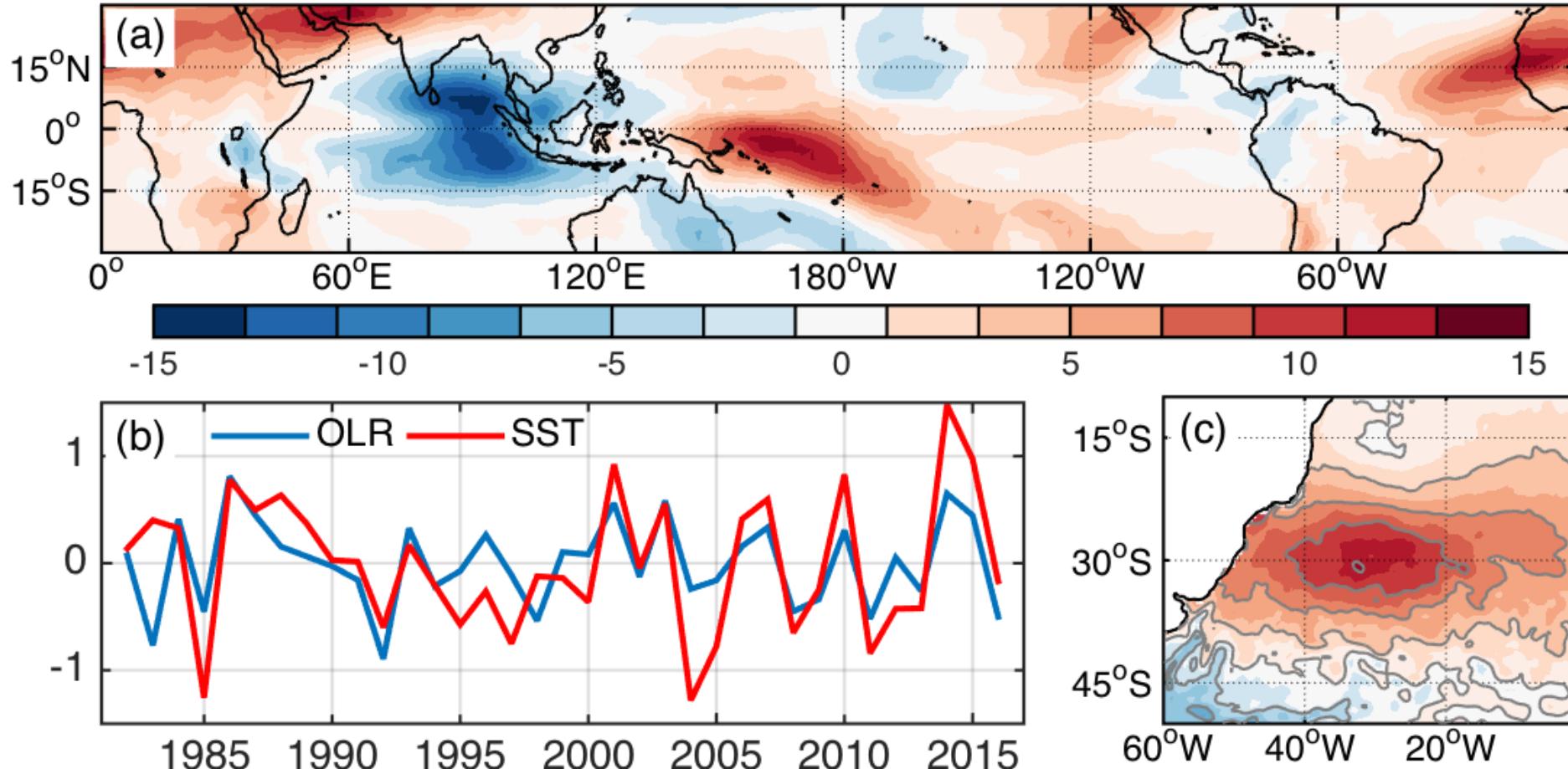
Rodrigues & Woollings (2017, JCLIM)



Compound Events

Land-Ocean Compound

MCA OLR-SST (1982-2016)

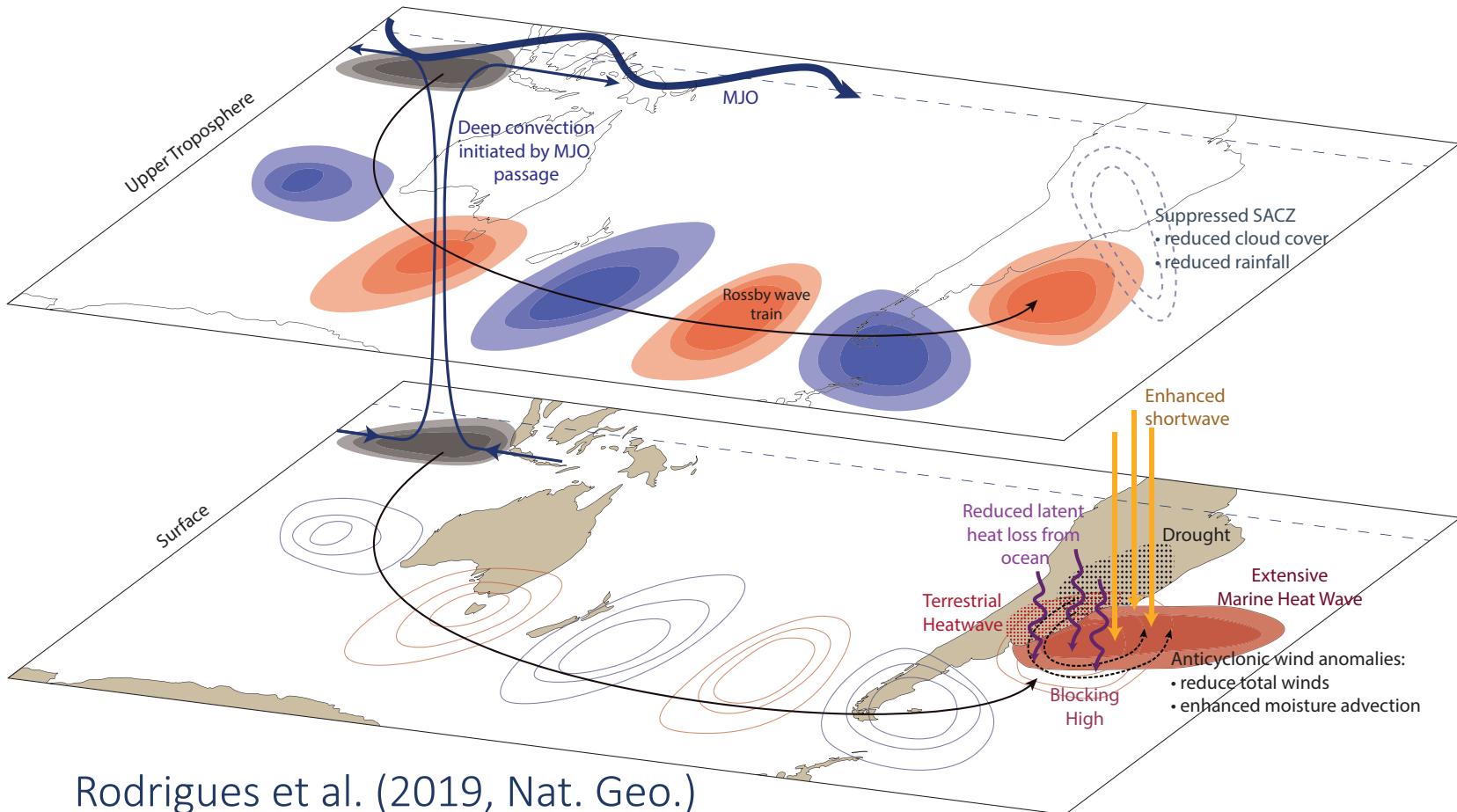


MJO Phases	1	2	3	4	5	6	7	8
MHW Frequency (%)	10	20	14	8	13	13	10	12



Compound Events

Land-Ocean Compound



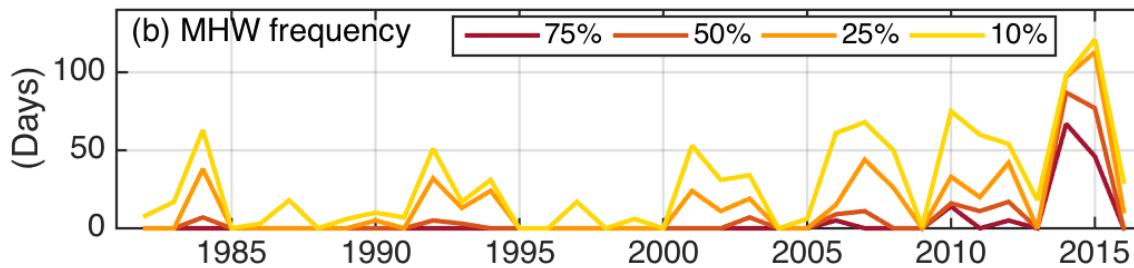
Rodrigues et al. (2019, Nat. Geo.)

- ✓ Droughts, marine and land heatwaves have the same cause
- ✓ Persistent high-pressure system (anticyclonic circulation)
- ✓ They can be remotely triggered (convection Indian Ocean – MJO)



Compound Events

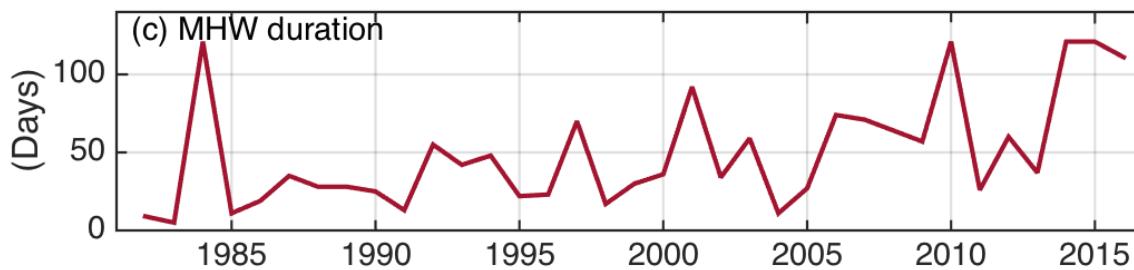
Frequency



✓ Trends per decade

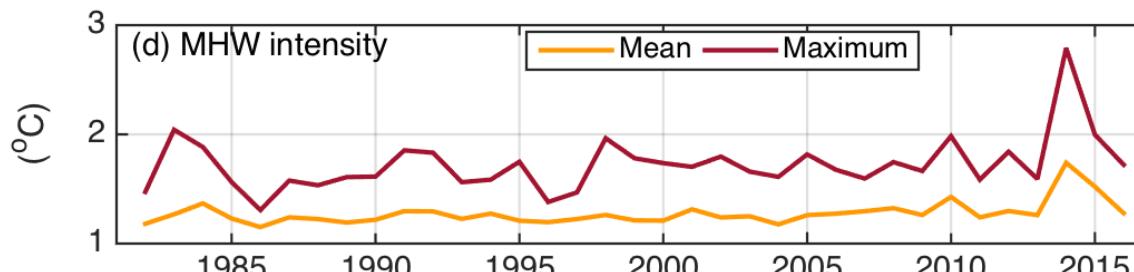
+8.4 days per year (50%)

Duration



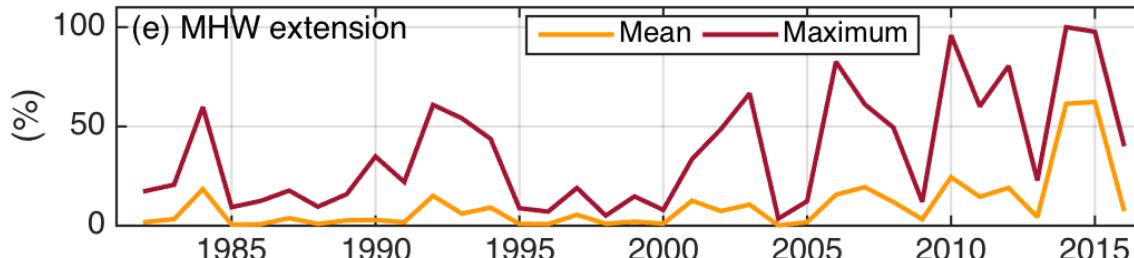
+18 days

Intensity



+0.05°C

Extension

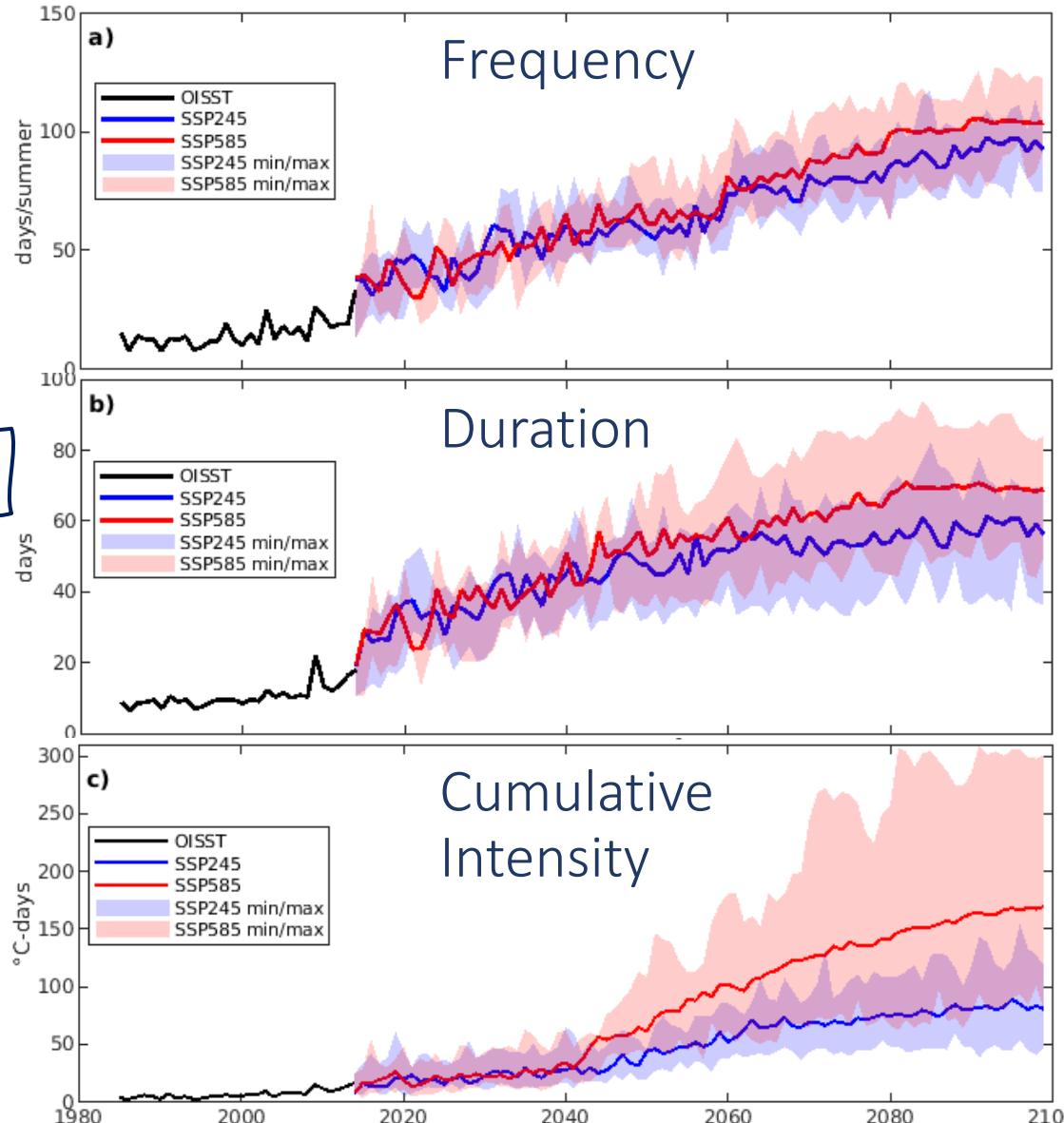


+7%



Compound Events

CMIP6



- ✓ The frequency, duration and intensity of marine heatwaves will **significantly increase** for the next decades in the western South Atlantic.
- ✓ The greatest trends in the marine heatwave characteristics occur during **the period of 2021–2050** and not by the end of the 21st century.
- ✓ The future trends are driven by the long-term warming and the **intensification of atmospheric blocking** over the region.

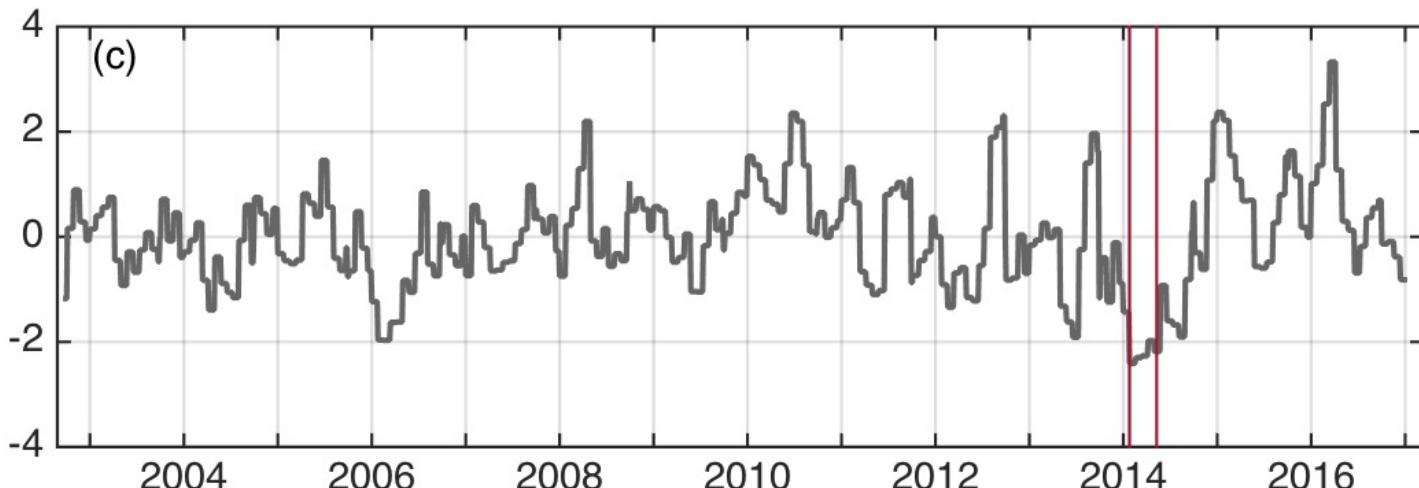
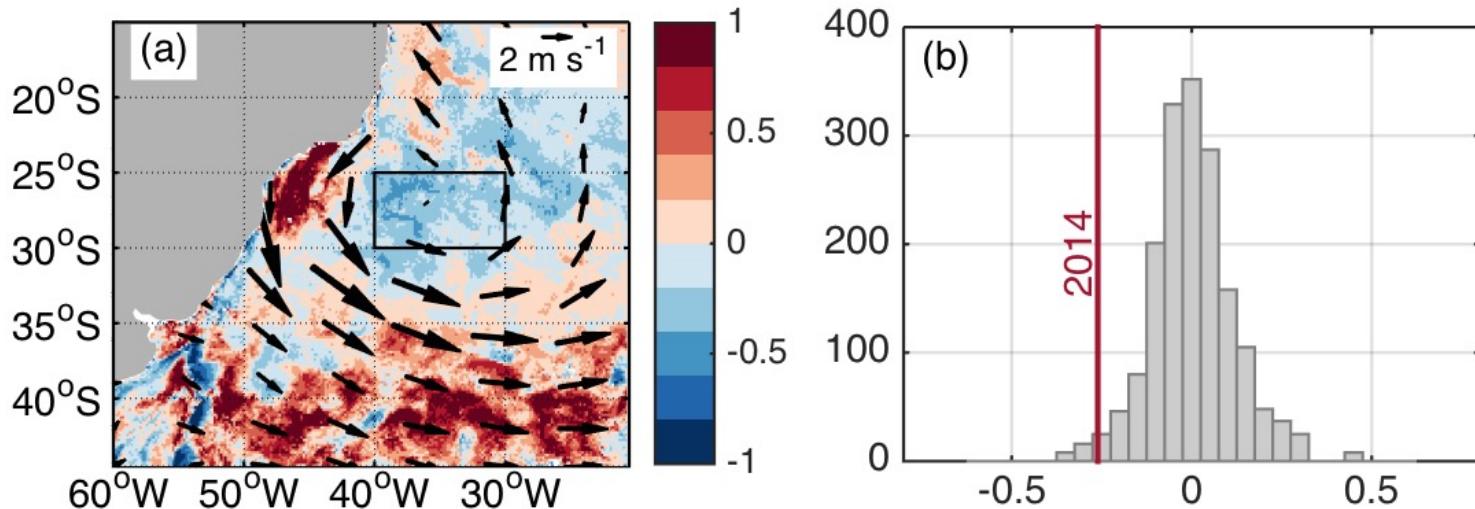
Costa & Rodrigues (2021, GRL)



Compound Events

Land-Ocean Compound

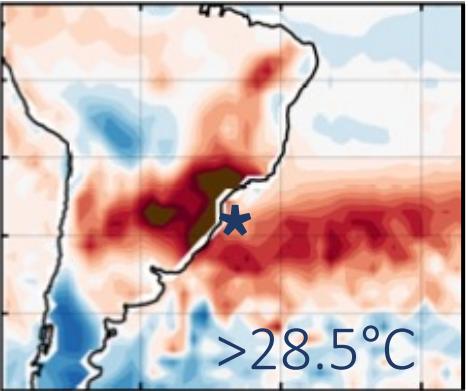
Ocean Colour
Impact (mg/m^3)





Compound Events

Land-Ocean Compound



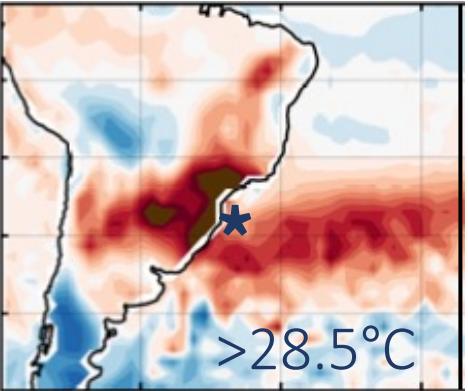
Clam - Vongole
(Anomalocardia flexuosa)





Compound Events

Land-Ocean Compound

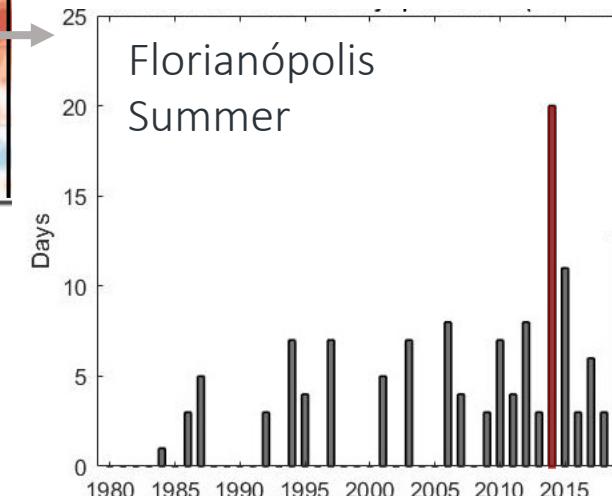
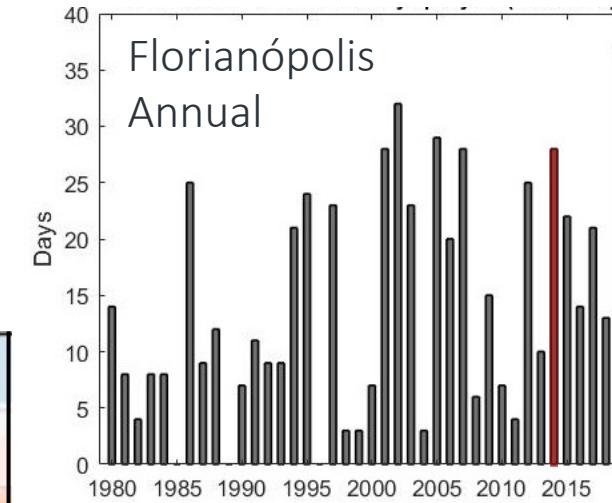
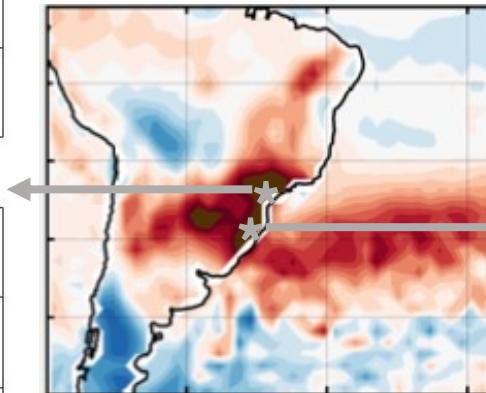
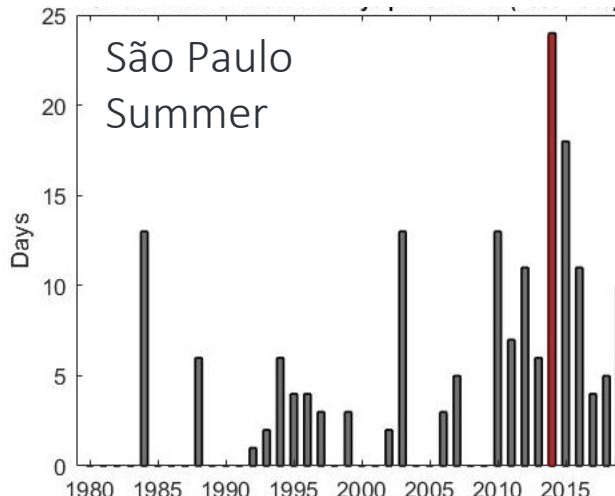
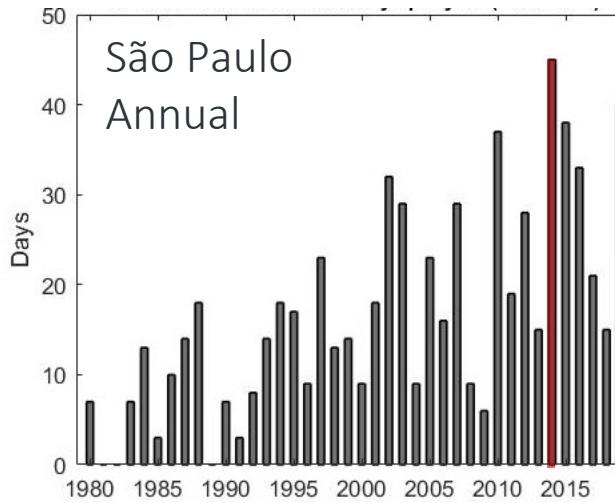




Compound Events

Land-Ocean Compound

Heatwaves



Methodology by Perkins & Alexander (2013)



Compound Events

Land-Ocean Compound



50 MIL ATINGIDOS

Governo decreta racionamento de água

© Giovanni Battista

Dias (PT) descreveu calamidade de água no norte do RJ, no sudeste e no Piauí, com 10 mil mortes e 130 mil desabrigados por famílias de a cada. Com recomendação da Organização das Nações Unidas (ONU), puxou a Temer em 2016, que abriu 20 mil habitações para moradores da região, mas só abriu 15% de sua capacidade, e os cemitérios lotados. Ele realizou algumas obras na bacia, mas manteve os sistemas destruídos pelo lodo.

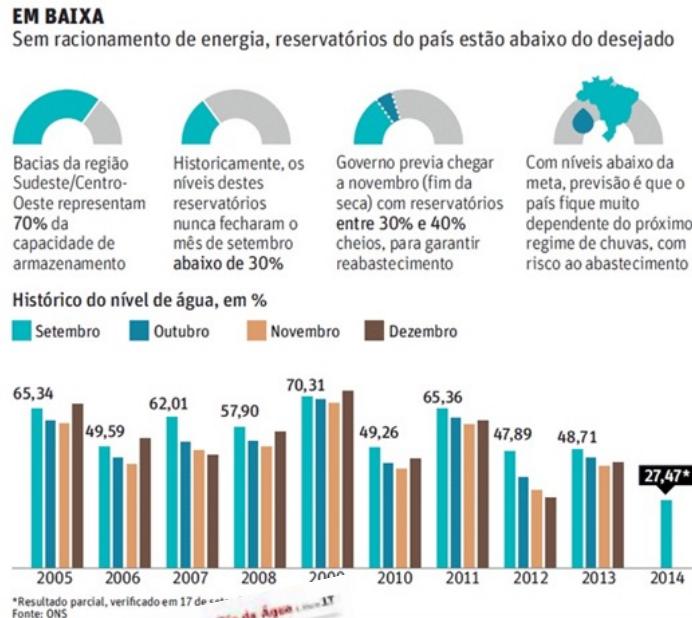
BARRA
Burrage
apenas
de amar.
O bá-
pito d-
180-000
nas Te-
mpos de

A photograph showing a person sitting on a large sand dune, looking out over a body of water under a clear blue sky.

BARRAGEM PAUL está com apenas 5% de sua capacidade. Barragem de Paul, que tem apenas 15% da sua capacidade de armazenamento de água. Os 10 mil habitantes atingiram com o encerramento das águas do morro de São Luís, Teresópolis, Rio, RJ. 06/03/2014.

que não tem em Plaza N. De. 105 que a Barragem de Plaza é um significado e método de interesse sócio-económico. Se é legítima a barragem existir, o que não interessaria? O problema seria então a natureza das duas propostas: qual é a mais adequada ao contexto social e ambiental do Rio Tejo? E qual é a mais viável para a solução do problema?

Nova da Paul, Europa Grande, além do passado Manoelinho. "Grande promessa das periferias, consideradas o futuro dos grandes e que têm sido apoiada por parte da comunidade, da academia, e que tem um grande potencial de crescimento", diz o professor.



**Compartilhar a água
é o desafio mundial**

Crise exige novos hábitos

Momento impõe revisão de rotinas e atitudes em casa, nas finanças e no trabalho

ESPECIAL

Mude o comportamento

Mude o comportamento

Não desperdice

**Antes de comprar,
eles pouparam**

TV à cabo
atendeu bem
nos testes
desenvolvidos
pela Agência
de Defesa
Consumidor

Renegociação
O prefeito Marcelo Crivella, em uma matinada sobretudo prestigiada por cidadãos que não conseguiram pagar suas contas de água, fez um anúncio que pode ser considerado de grande relevância para o futuro da capital carioca. O prefeito, que é deputado estadual, convocou os deputados estaduais para discutir a possibilidade de renegociação das dívidas de água e luz dos moradores da capital. A reunião foi realizada no auditório da Assembleia Legislativa do Rio de Janeiro, na sede da Alerj, e contou com a participação de deputados de todos os partidos. O objetivo da reunião era discutir a possibilidade de renegociação das dívidas de água e luz dos moradores da capital. A reunião foi realizada no auditório da Assembleia Legislativa do Rio de Janeiro, na sede da Alerj, e contou com a participação de deputados de todos os partidos.

capacidade

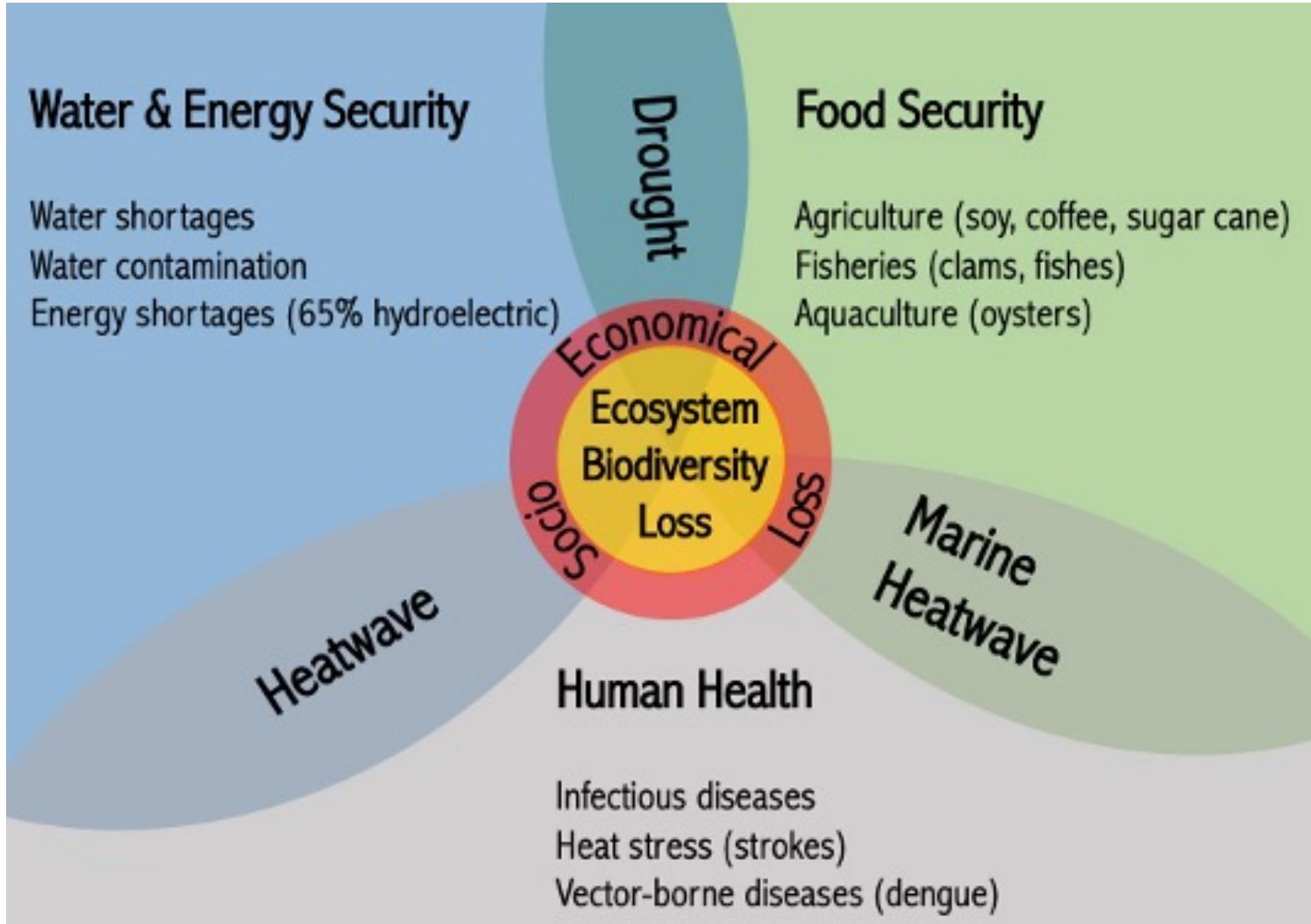
No entanto, não queremos dizer que a profissão de enfermeira é a única que deve ter capacidade de decisão. A profissão de enfermeira é grande e diversificada. Cada enfermeira tem seu próprio campo de atuação. Elas devem ter capacidade de decisão para atender às necessidades de seus pacientes. As enfermeiras devem ser capazes de tomar decisões informadas, baseadas em evidências científicas e em suas próprias habilidades profissionais.

“Acredito que é preciso ter uma visão de futuro, mas é preciso ter uma visão de presente e de passado”, ressalta o presidente da FecomercioSP, que destaca que “o Brasil tem que se reinventar”.



Compound Events

Land-Ocean Compound

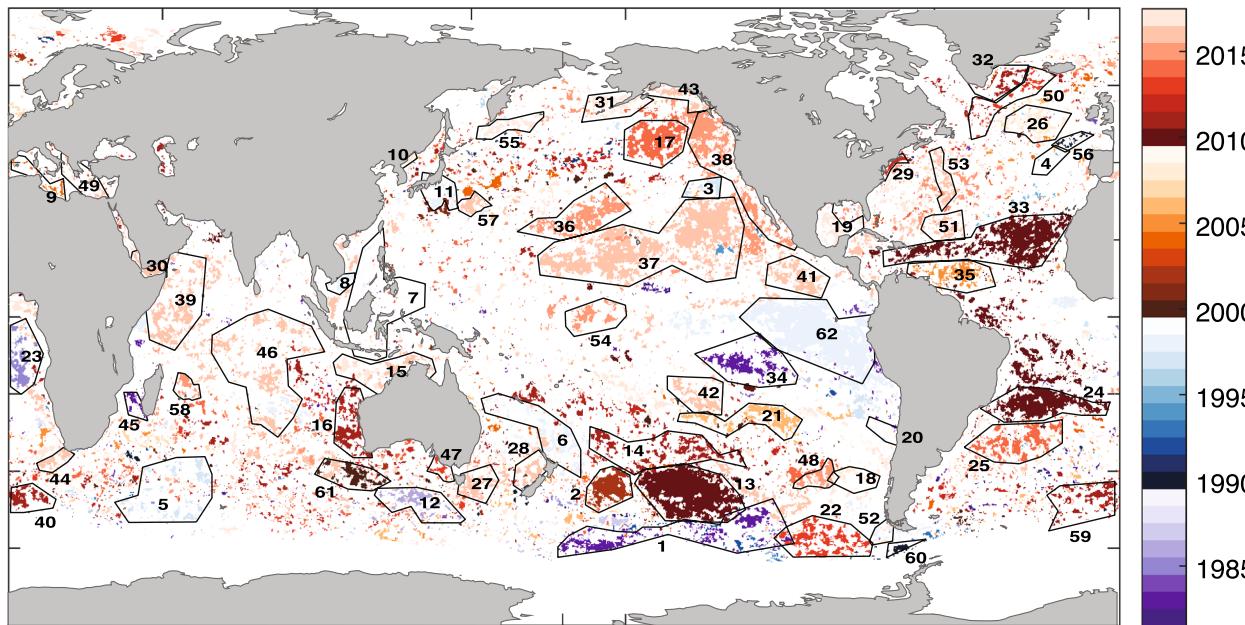




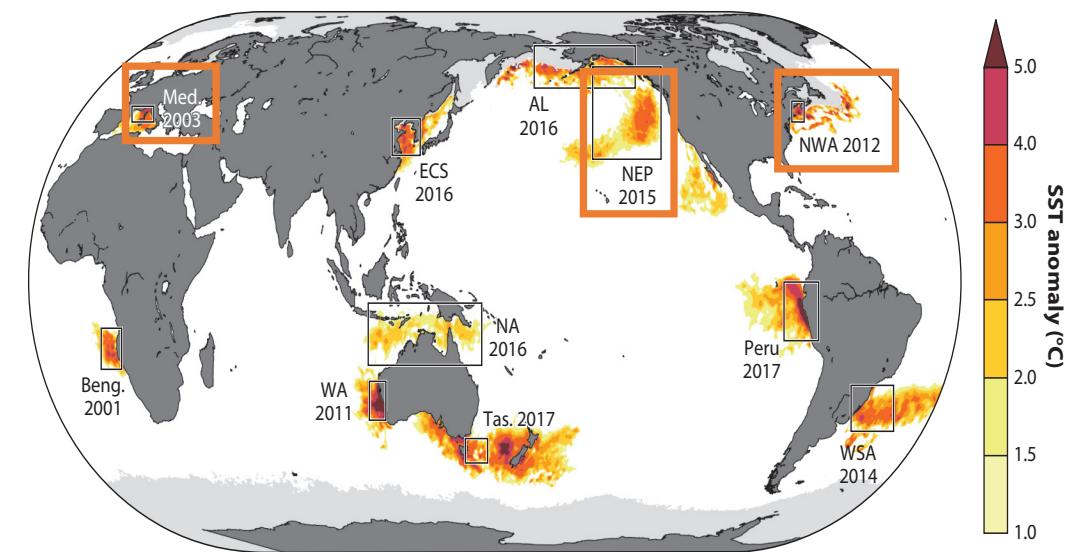
Compound Events

Land-Ocean Compound

Strongest and longest recorded MHW



✓ Similar drivers and impacts
Sen Gupta et al. (2020, Sci. Rep.)



- ✓ Mediterranean Sea 2003
- ✓ Northwest Atlantic 2012
- ✓ Northeast Pacific 2015 = The Blob

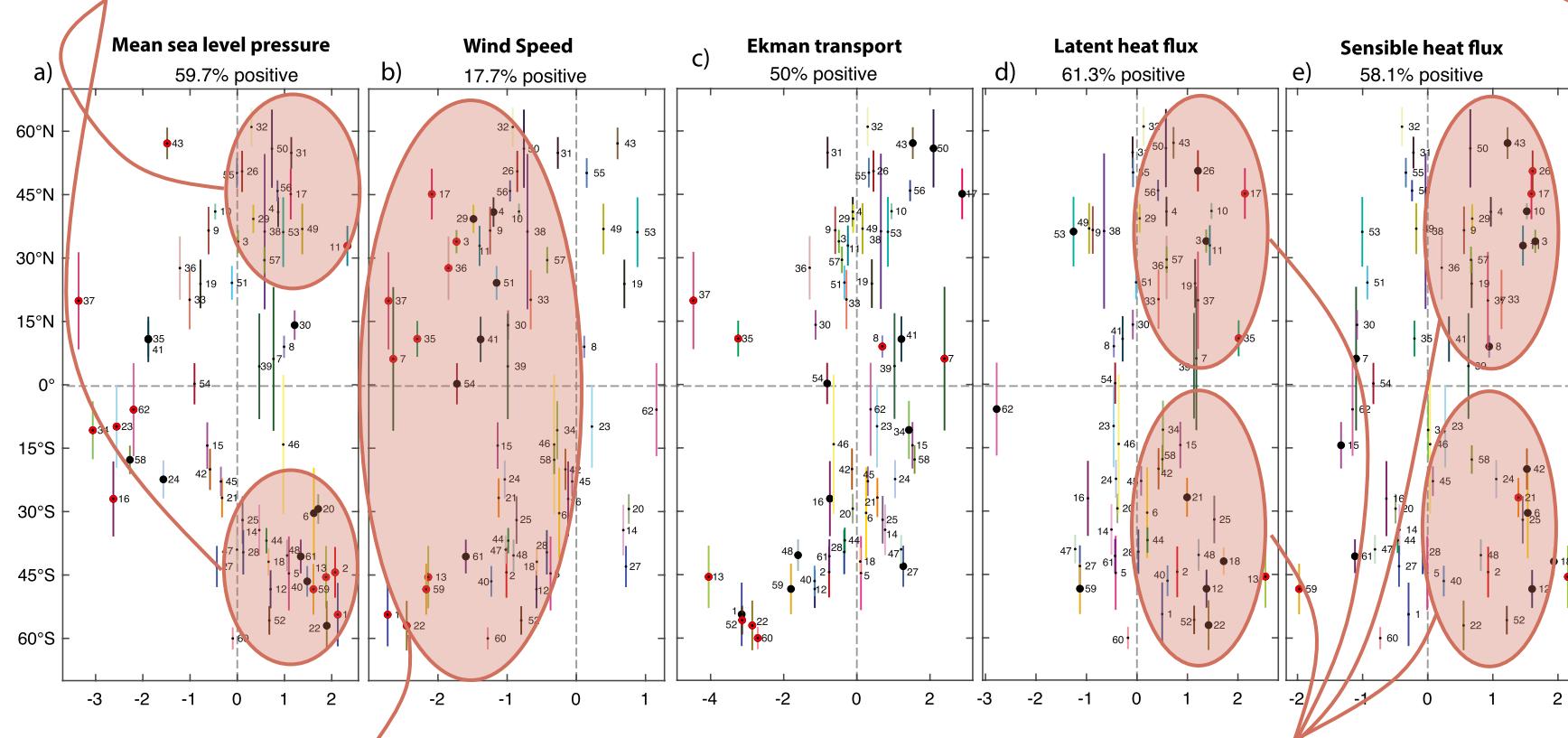


Compound Events

Land-Ocean Compound

Sen Gupta et al. (2020, Sci. Rep.)

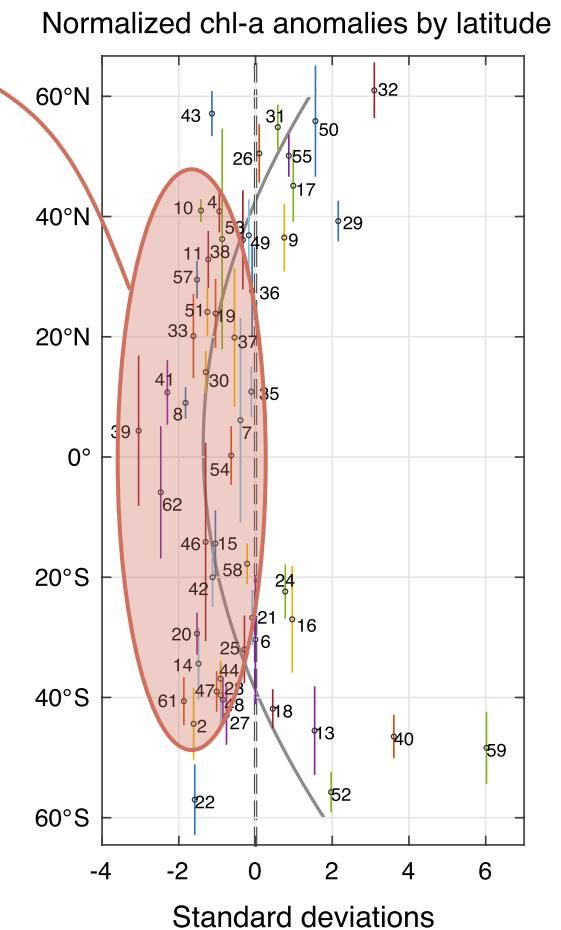
1 Almost all extratropical MHW associated with **high-pressure systems**



2 Almost all MHW associated with **weak winds**

4 Reduced productivity at lower latitudes

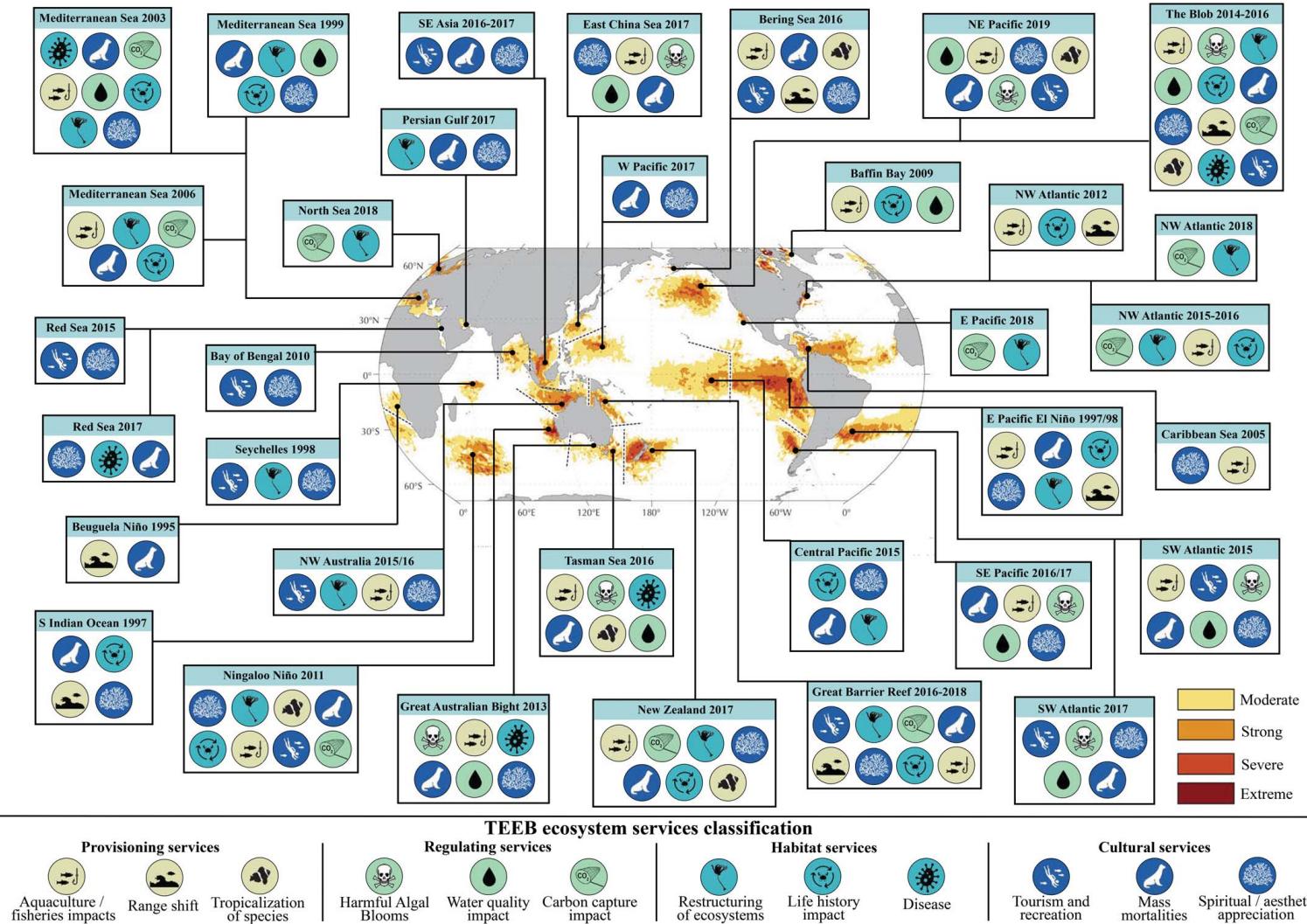
3 Many MHW associated with **weaker evaporative (sensible) cooling**





Compound Events

Land-Ocean Compound



“Reported economic costs of individual MHW events exceed US\$800 million in direct losses or >US\$3.1 billion in indirect losses of ecosystem services for multiple years.”

Smith et al. (2021, Science)



Compound Events

Ocean Compound

- ✓ Marine Heatwaves
- ✓ Extremes of High Acidity
- ✓ Extremes of Low Oxygen
- ✓ Extremes of Low Productivity

nature

Biogeochemical extremes and compound events in the ocean

Nicolas Gruber , Philip W. Boyd, Thomas L. Frölicher & Meike Vogt

nature communications

Compound marine heatwaves and ocean acidity extremes

Friedrich A. Burger , Jens Terhaar & Thomas L. Frölicher

Warm waters

↑ [H+] via changes in the
carbonate chemistry
equilibrium

↓ O₂ via reduction of
solubility in surface
waters

↓ Primary productivity
via reduction of
nutrients



Compound Events

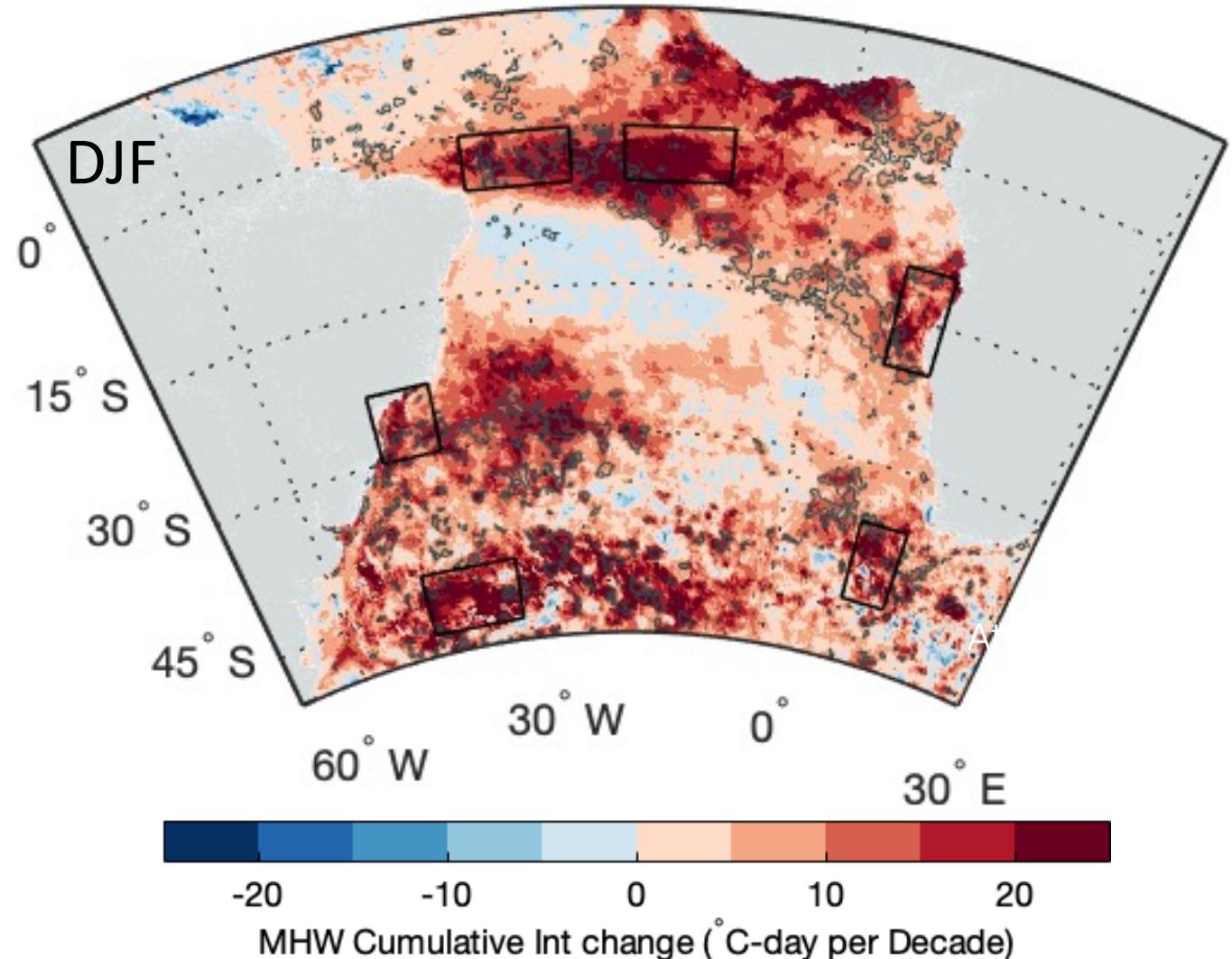
Ocean Compound

Baseline 1982-2020
Hobday et al. (2016, Prog. Oceanogr.)

Marine Heatwaves (MHW)
cumulative intensity
 $\approx \sum$ daily intensity anomalies

Thomas Frölicher Noel Keenlyside
Friedrich Burger Alistair Hobday

Trends (1982-2020)



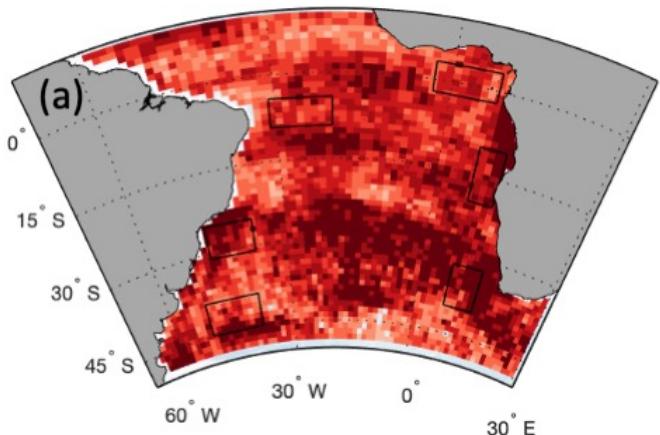


Compound Events

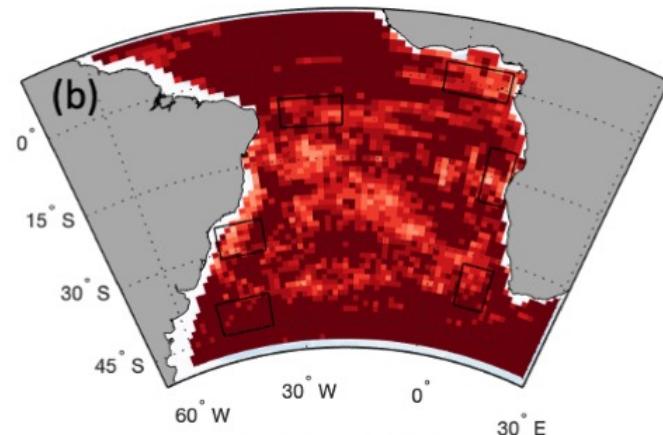
Ocean Compound

1999-2008

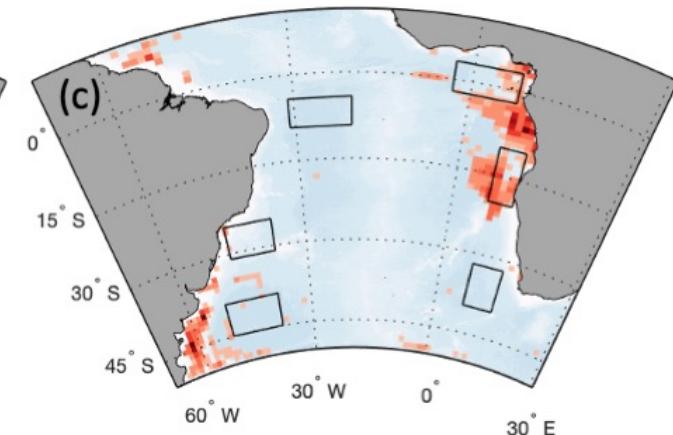
MHW



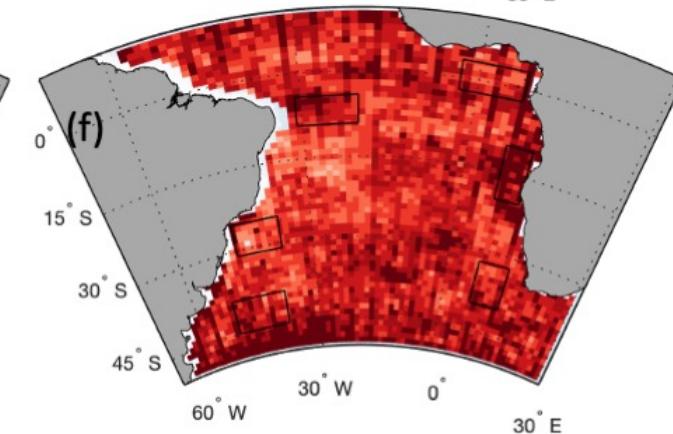
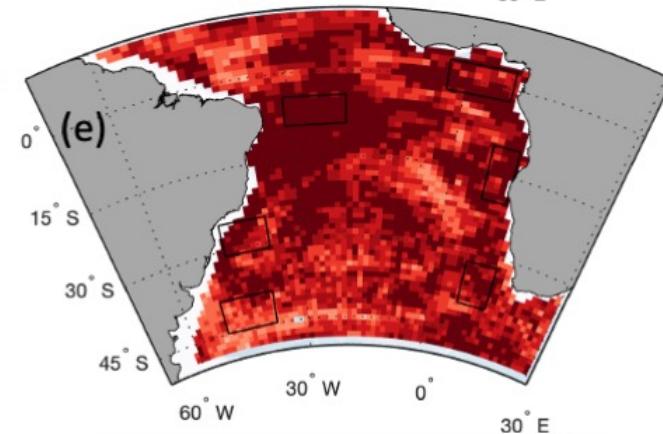
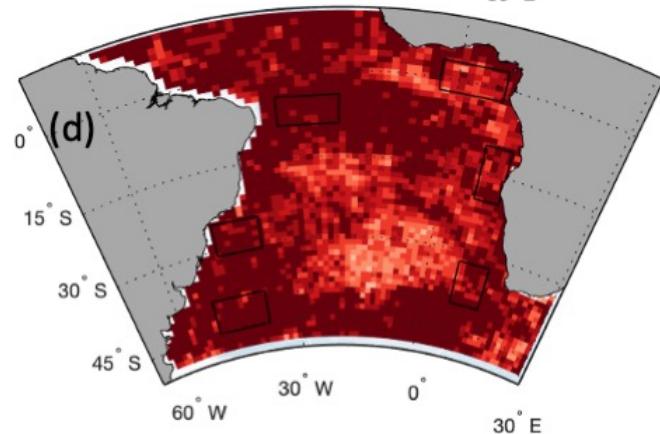
Low Chlorophyll



High Acidity



2009-2018

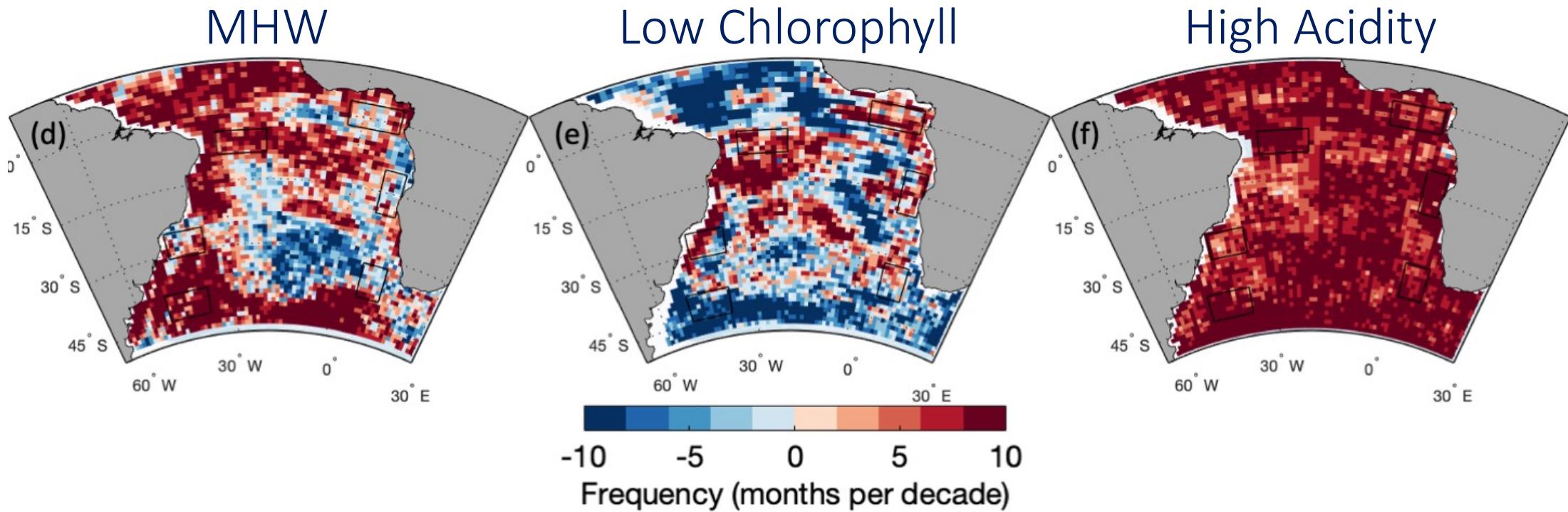


0 5 10
Frequency (months per decade)



Compound Events

Ocean Compound



(2009-2018) – (1999-2008)

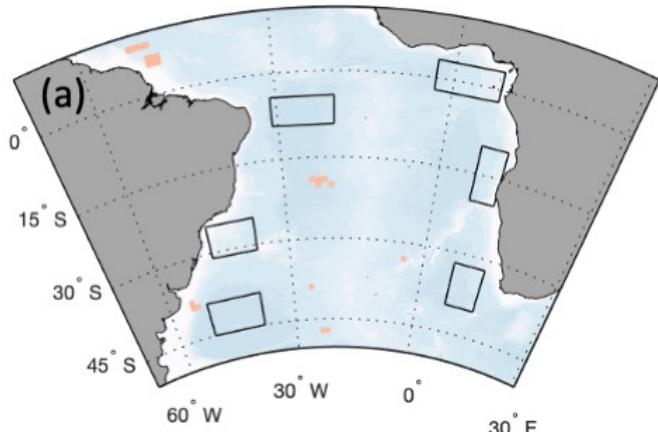


Compound Events

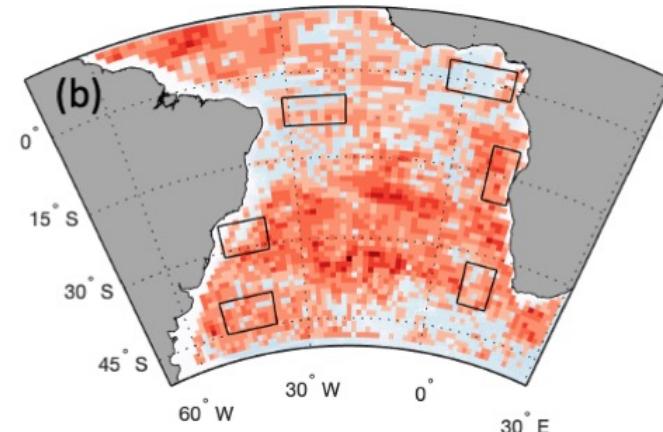
Ocean Compound

1999-2008

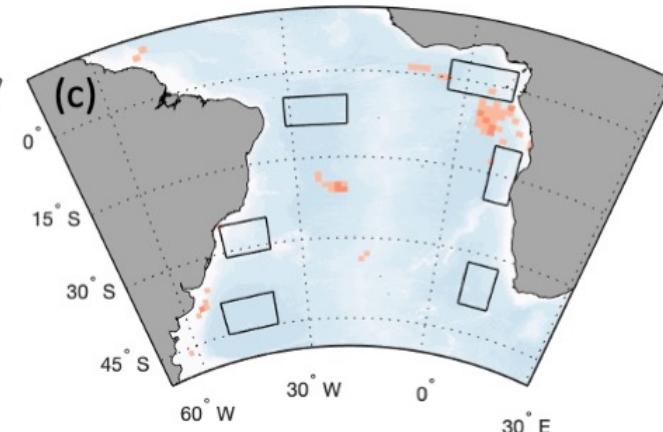
MHW + LC + HA



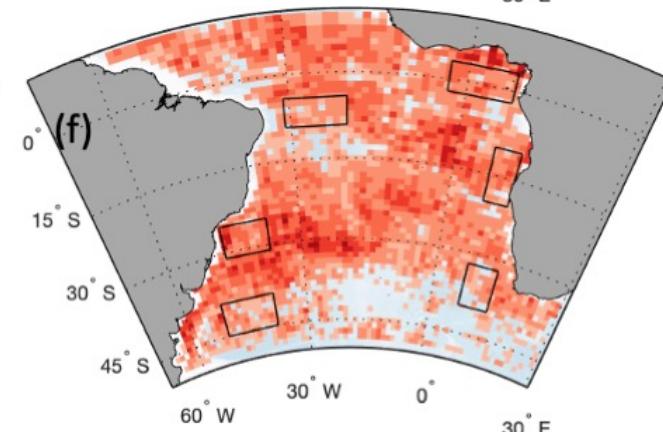
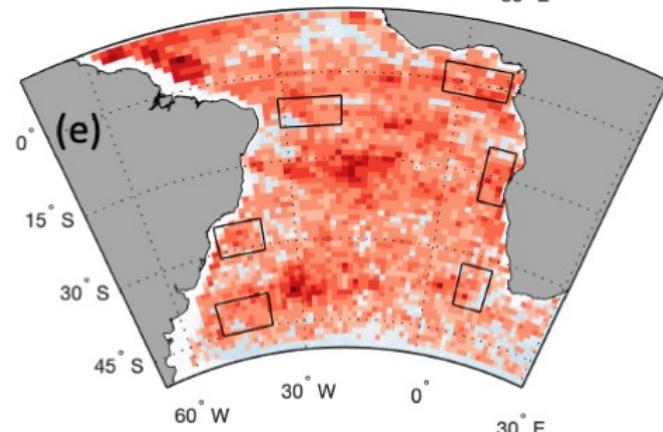
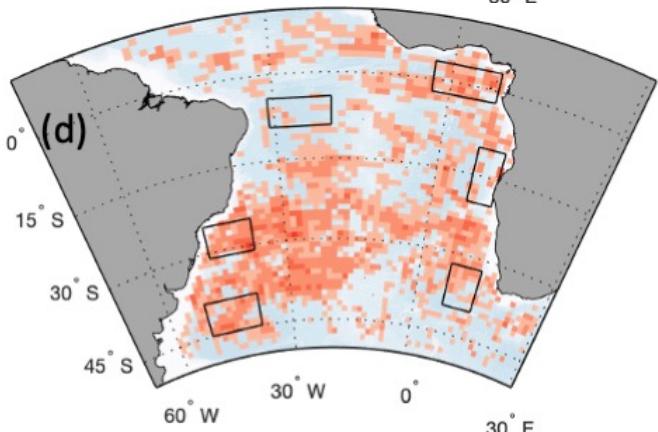
MHW + LC



MHW + HA



2009-2018



LC = Low Chlorophyll

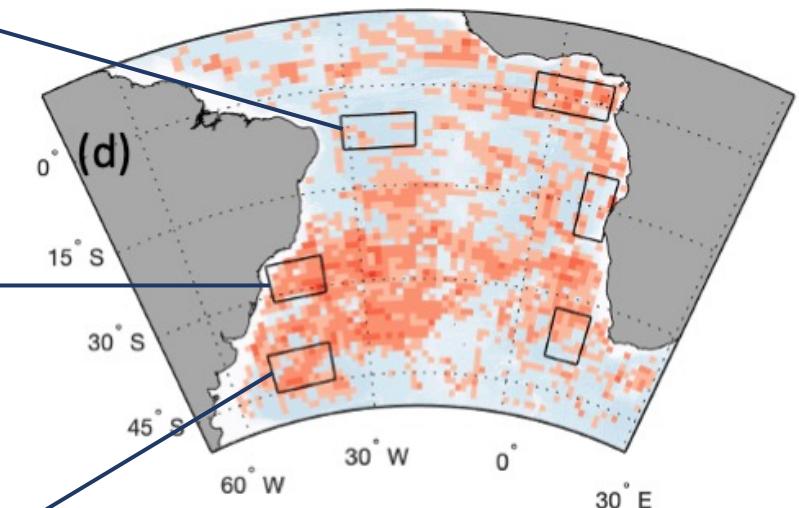
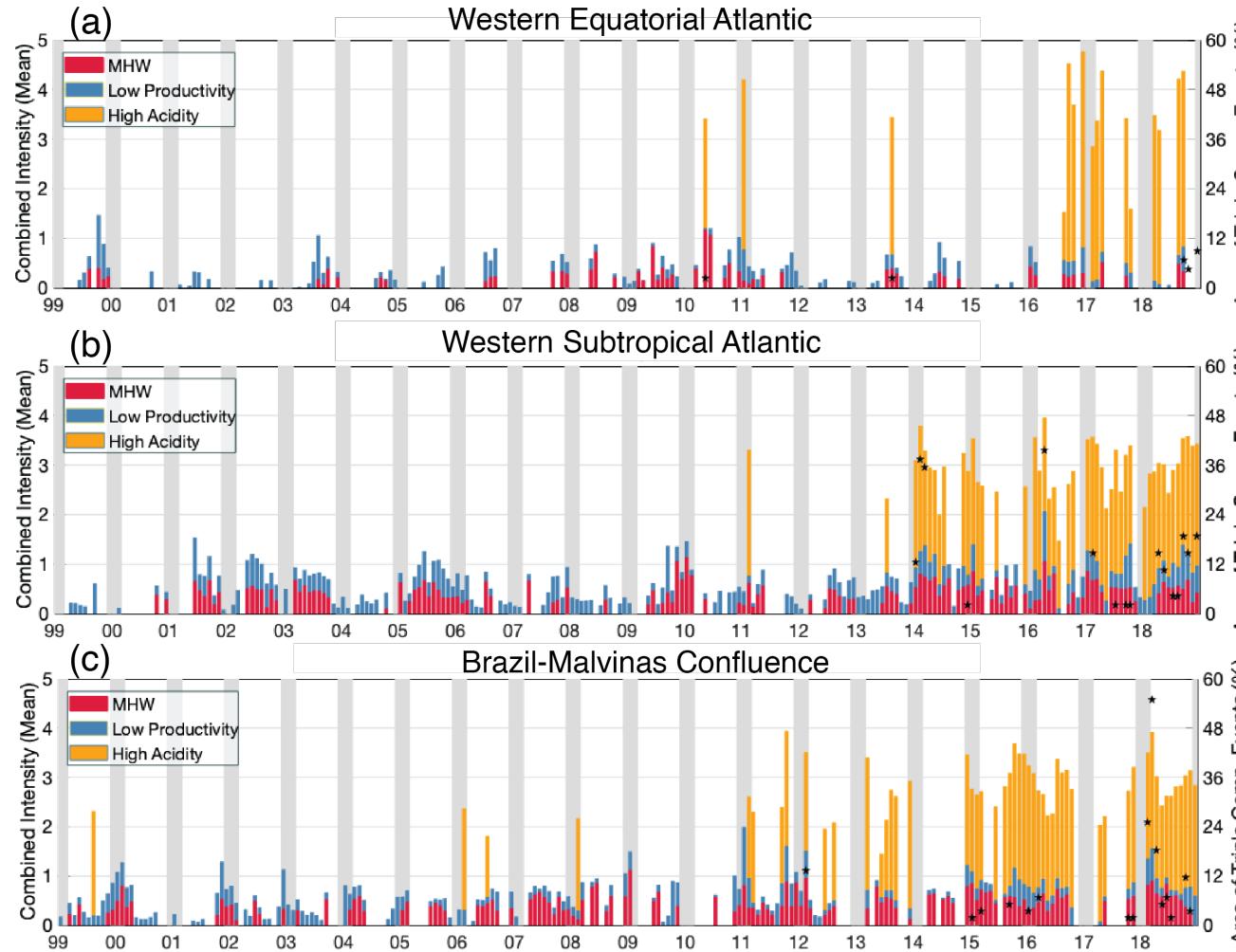
HA = High Acidity

0 5 10
Frequency (months per decade)



Compound Events

Triple Compound: MHW + Low Chlorophyll + High Acidity

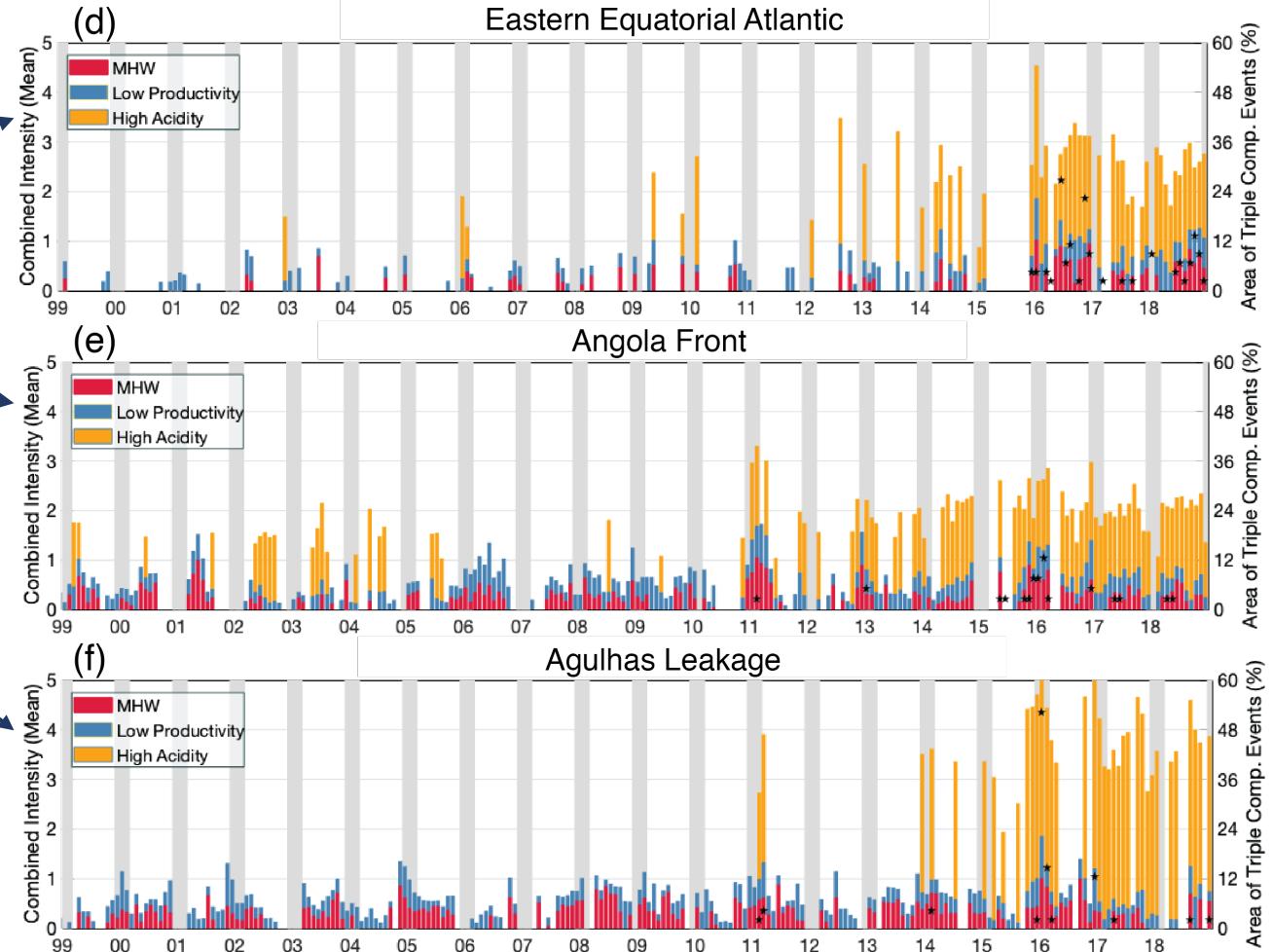
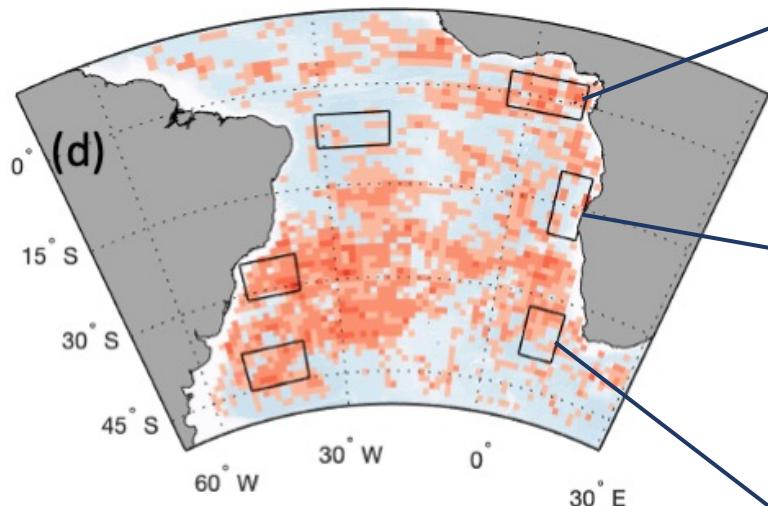


Values displayed are normalised by their standard deviation. Asterisks indicate the area simultaneously covered by the triple compound in each region (in percentage, right y-axis)



Compound Events

Triple Compound: MHW + Low Chlorophyll + High Acidity





Compound Events

Ocean Compound

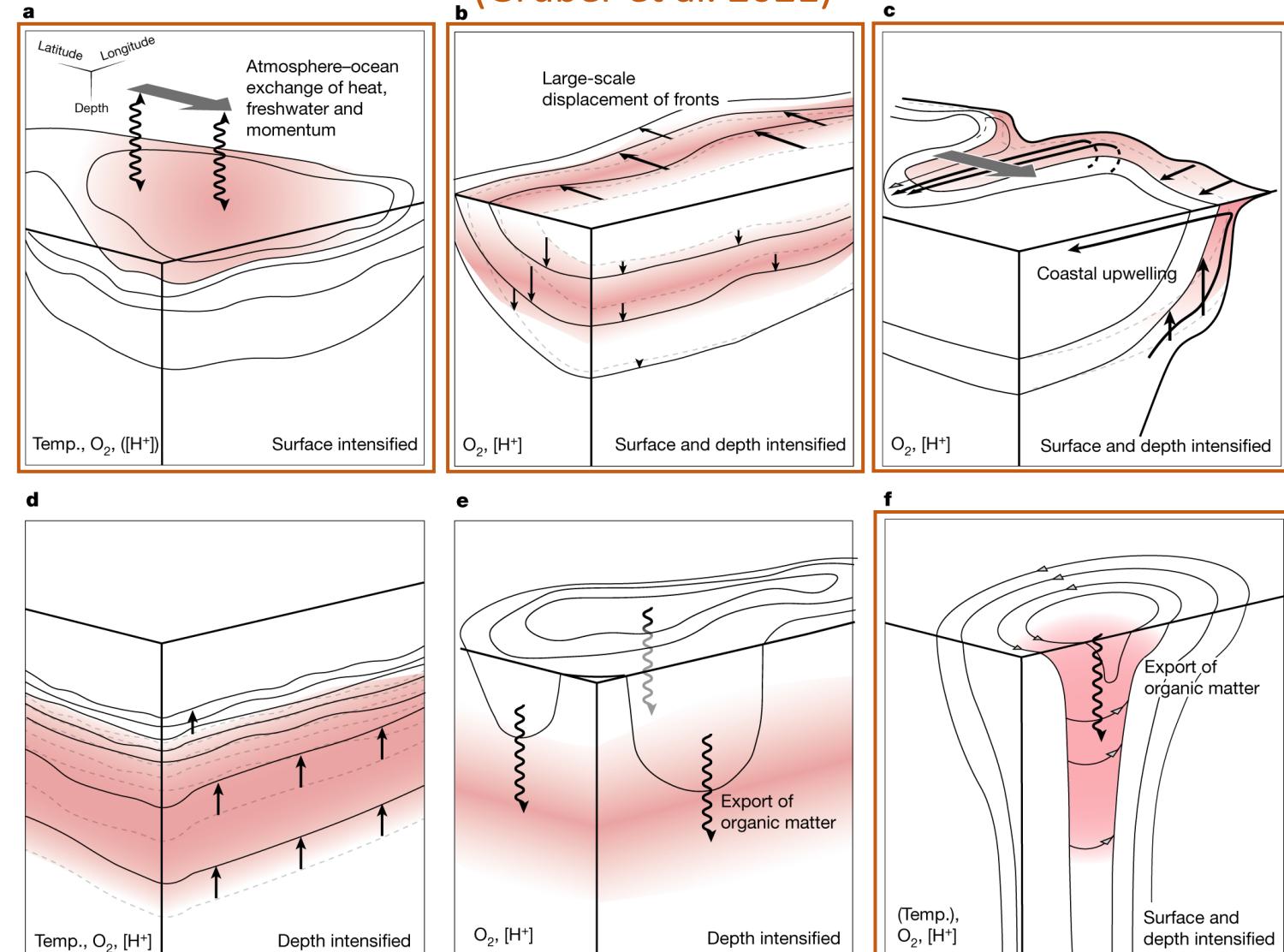
(a) Air-sea Interaction:
Western Equatorial and
Subtropical Atlantic

(b) Front Displacement:
Angola and Brazil-
Malvinas Confluence

(c) Upwelling: Eastern
Equatorial Atlantic and
Angola Front

(f) Eddie Trapping:
Agulhas Leakage

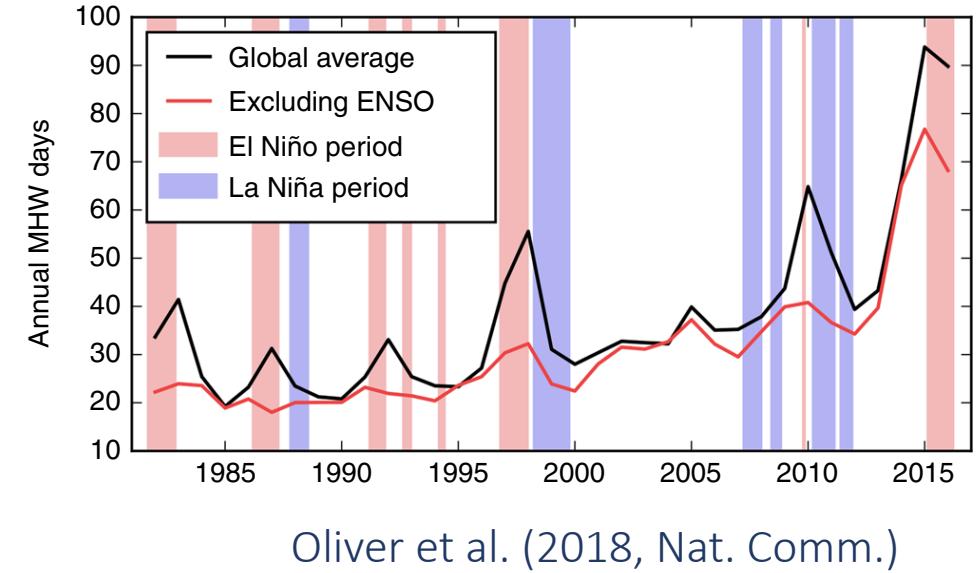
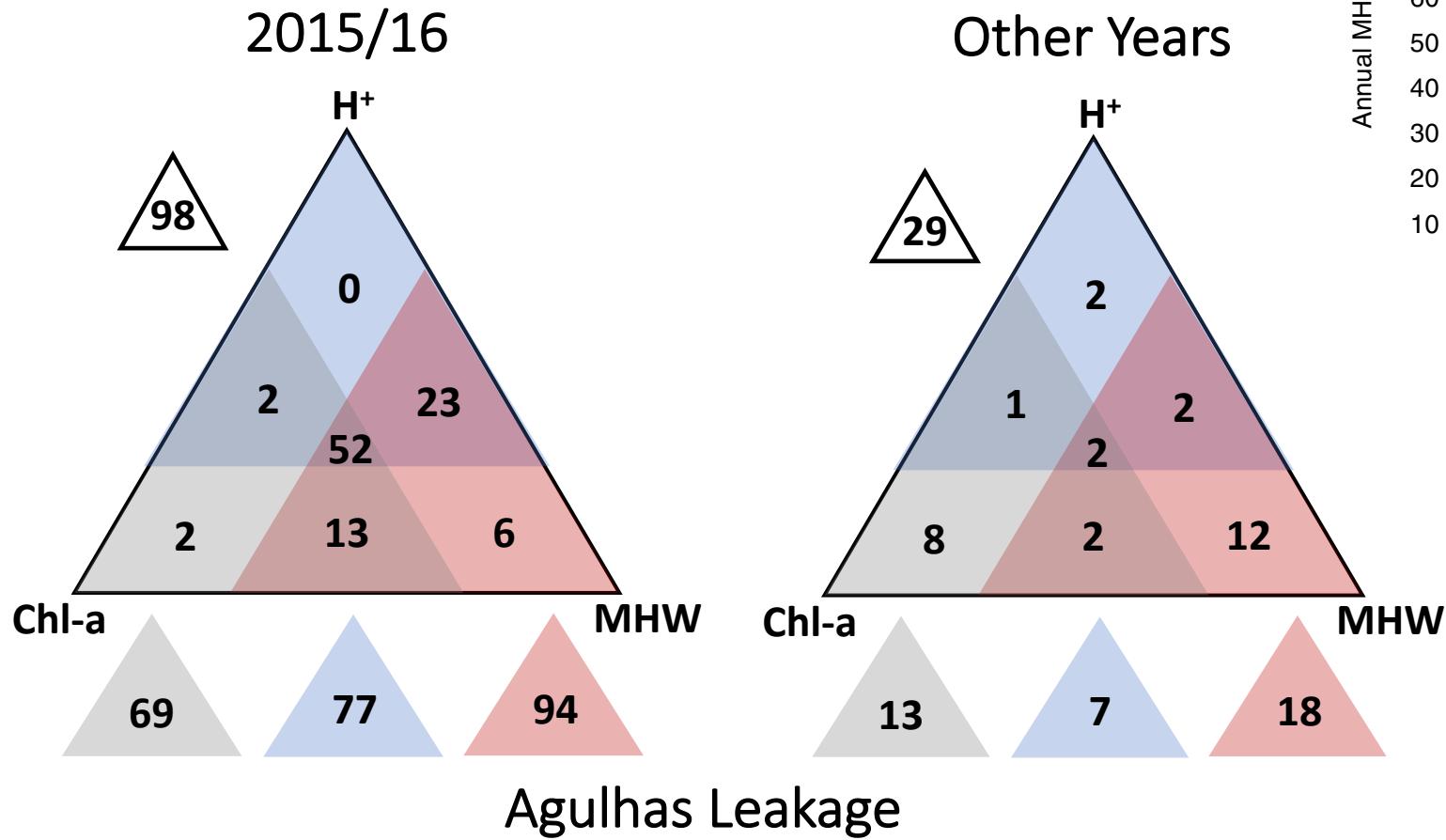
(Gruber et al. 2021)





Compound Events

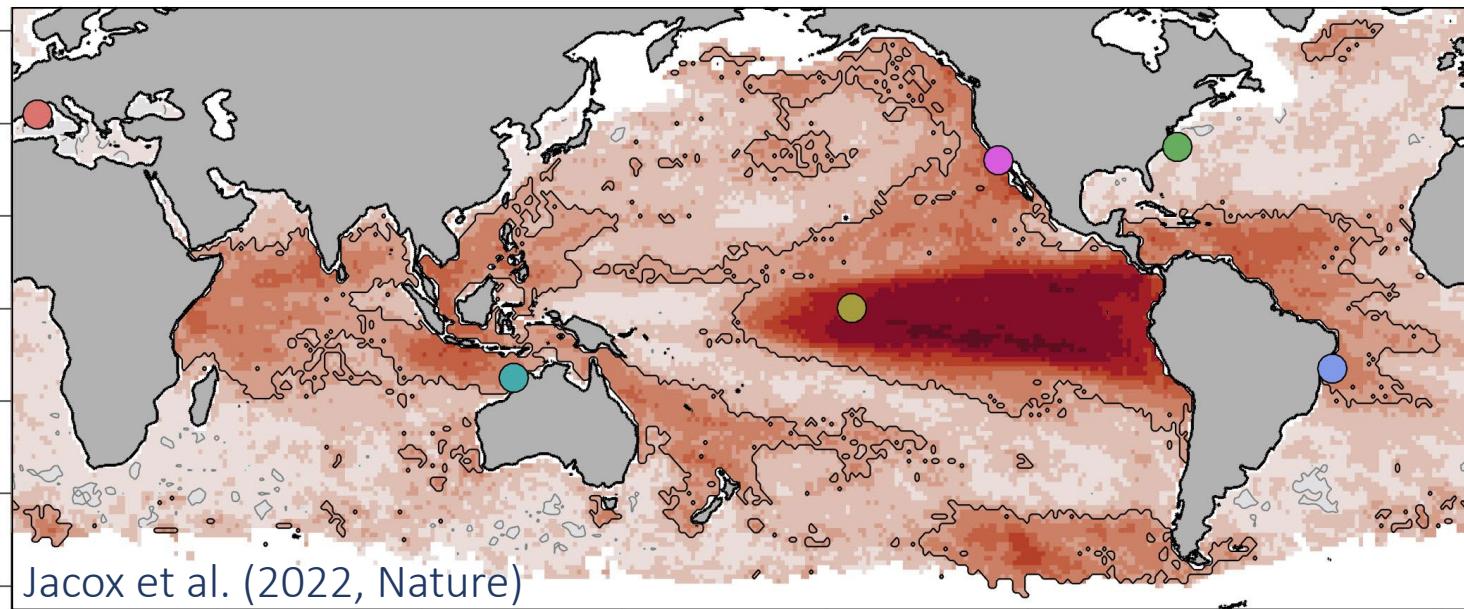
Ocean Compound



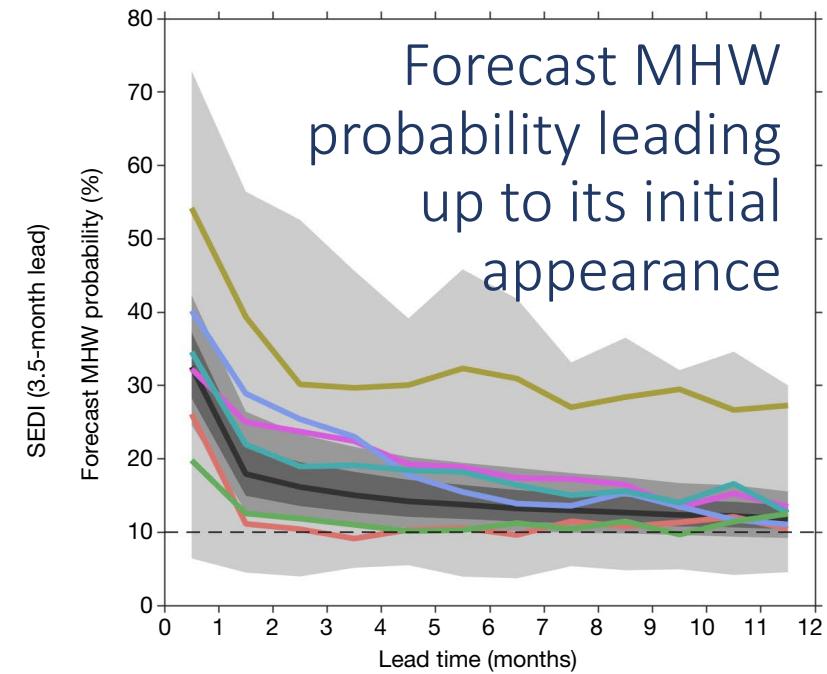


Compound Events

Seasonal Forecasts



MHW forecast skill with lead time of 3.5 months



Successful **adaptation** depends greatly on effective forecast

Compound extremes – offer an opportunity to advance our knowledge about MHW



Compound Events

Implication



- ✓ Ocean warming combined with acidification can **negatively affect** many species' survival, growth, development and shifts in community structure



- ✓ Several studies show that their negative impact can be **mitigated** by an increase in food availability



- ✓ However, this is not possible when compound extremes of warming and high acidity **co-occur with low chlorophyll** concentrations, i.e., a decrease in food availability



Compound Events

Gaps & Opportunities



Land and ocean compound extremes need to be **considered together**



They often have the **same drivers**, and our knowledge of land extremes is more advanced



Their **compound impacts** can be nonlinear, amplifying socioeconomic losses



The challenge of (ocean) **data restriction**

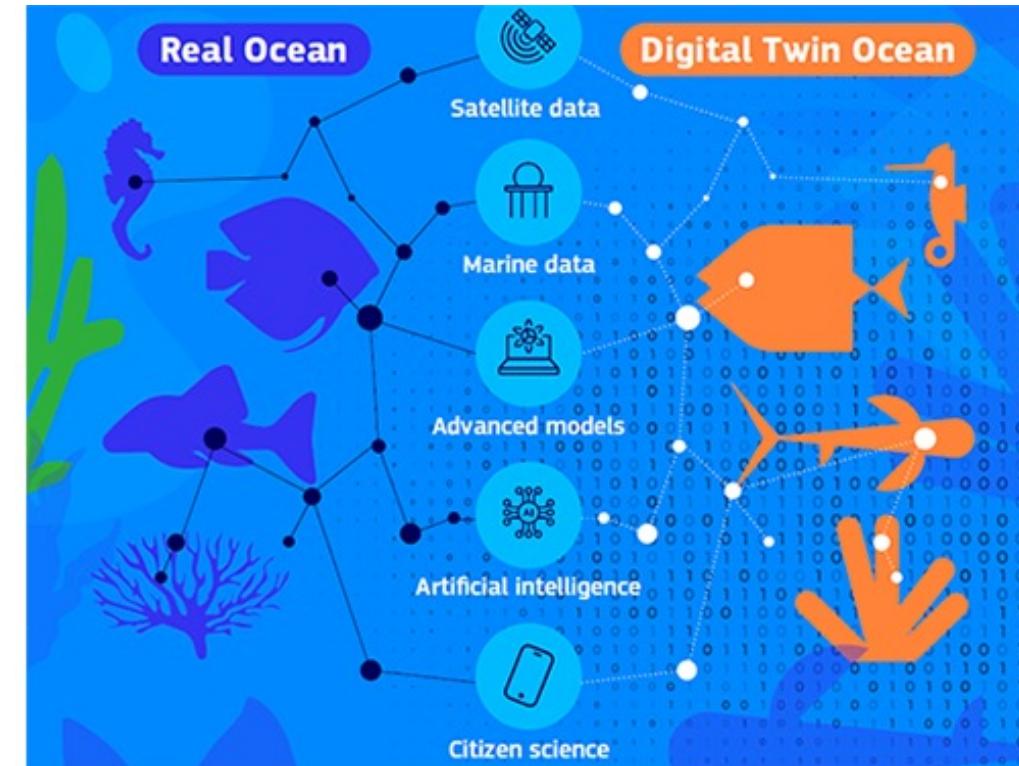


Achievable for **regional studies**



Compound Events

Gaps & Opportunities

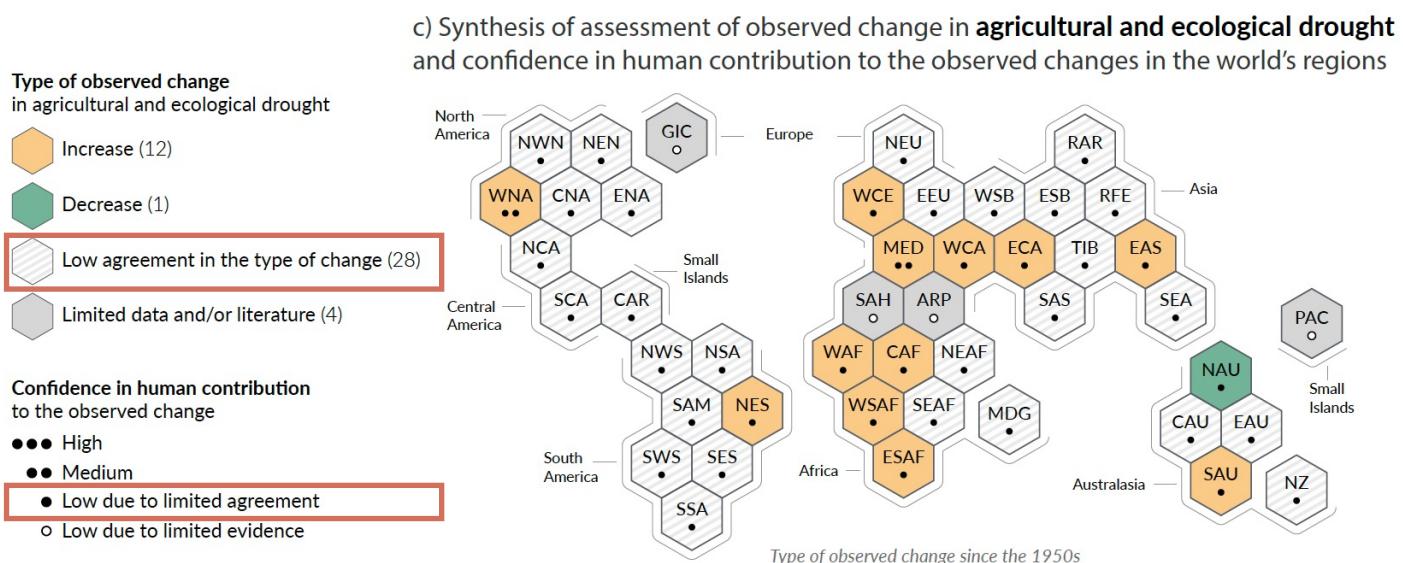


Digital Earth is a concept of an interactive digital replica of the entire planet that can facilitate a shared understanding of the multiple relationships between the physical and natural environments and society.



Compound Events

Gaps & Opportunities



Traditional ways of producing aggregated climate information can leave climate scientists empty-handed for many regions of the world

Yet there can be a wealth of local climate knowledge (e.g. Chapter 10 of IPCC AR6)

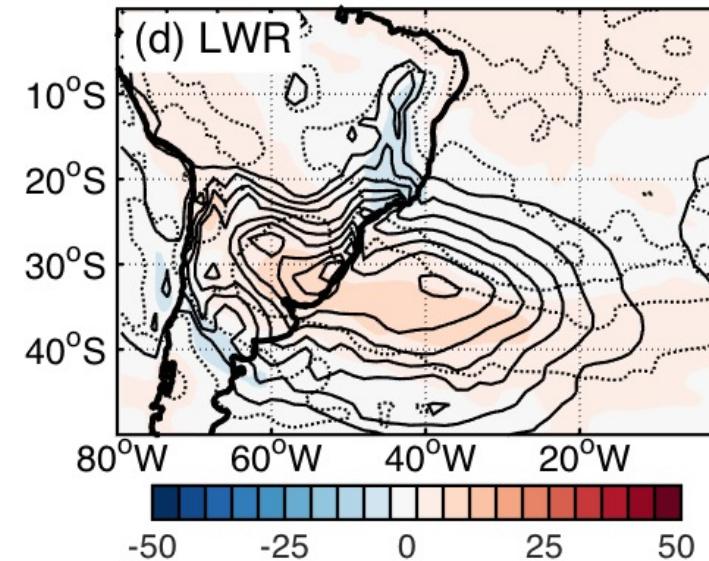
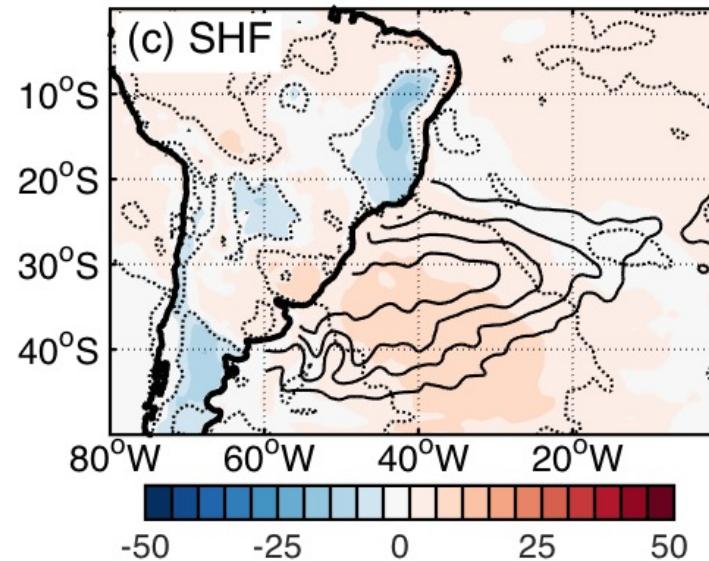
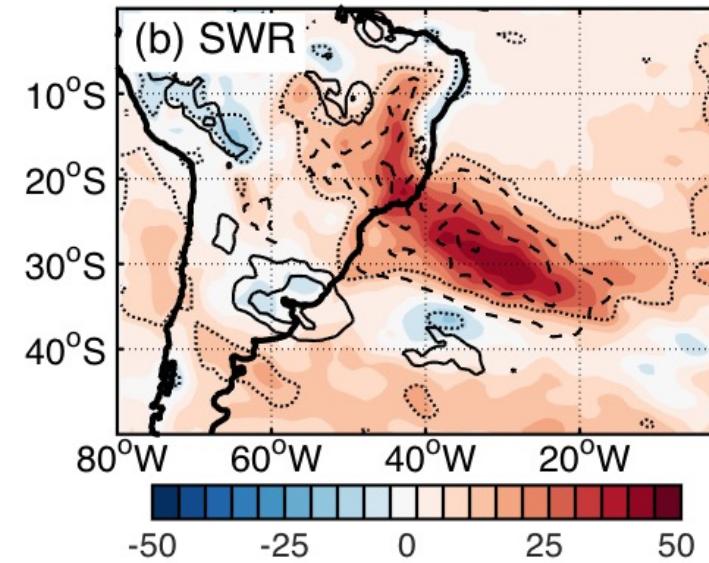
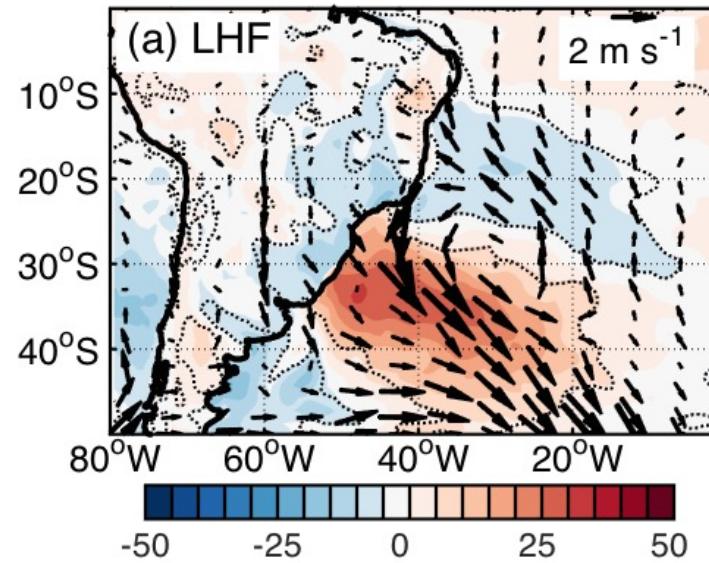
The background of the slide features a high-angle aerial photograph of the ocean. The water is a deep blue, with white and light blue ripples and waves creating a textured pattern across the frame. A prominent whitecap is visible in the lower right quadrant.

Marine Heatwaves in the Context of Compound Extremes

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@rrrocean 



Compound Events



Surface Heat Fluxes

Rodrigues et al. (2019, Nat. Geo.)



Compound Events

Triple Compound: MHW + Low Chlorophyll + High Acidity

Confluence
Brazil-Malvinas

Angola Front

