Extreme events in agriculture: identification and impacts

Gianni Bellocchi

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UNIVERSITÀ DEGLI STUDI DI SASSARI

Ciclo di seminari del Dr Gianni Bellocchi, Visiting Professor

24 aprile 2015 ~ 08 maggio 2015, ore 11.30
Aula Pampaloni, Dipartimento Agraria, Viale Italia 39 - Sassari

Il Dr. Gianni Bellocchi, nell'ambito del programma Visiting Professor, terrà presso il Dipartimento di Agraria ciclo di seminari secondo il seguente calendario:

Venerdì 24 Aprile 2015 ore 11:30 - Vulnerabilità ai cambiamenti climatici dei prati-pascoli europei
Martedì 28 Aprile 2015 ore 15:00 - Valutazione di modelli di simulazione colturale
Venerdì 8 Maggio 2015 ore 11:30 - Eventi estremi in agricoltura: identificazione e impatti

Gianni Bellocchi è direttore di ricerca presso l'INRA - UREP (Institut National de la Recherche Agronomique - Unitè de Recherche sur l'Ecosysteme Prairial, Clermont-Ferrand, Francia). La sua attività di ricerca sulla modellizzazione agro-climatica e ambientale integra tematiche agronomiche, di fisiologia vegetale e di climatologia. Ha sviluppato modelli e indicatori per la valutazione degli impatti del clima su sistemi agro-ambientali.

Extreme events in agriculture: identification and impacts

Gianni BELLOCCHI

Grassland Research Ecosystem Unit
French National Institute for Agricultural Research

Clermont-Ferrand, France

08 May 2015
Sassari (Itay)

AFP

JAN. 21, 2014

East Coast Storm Brings Snow and Disruptions to the New York Region

Reuters

JAN 21, 2014

California suffering possibly its worst drought in a century

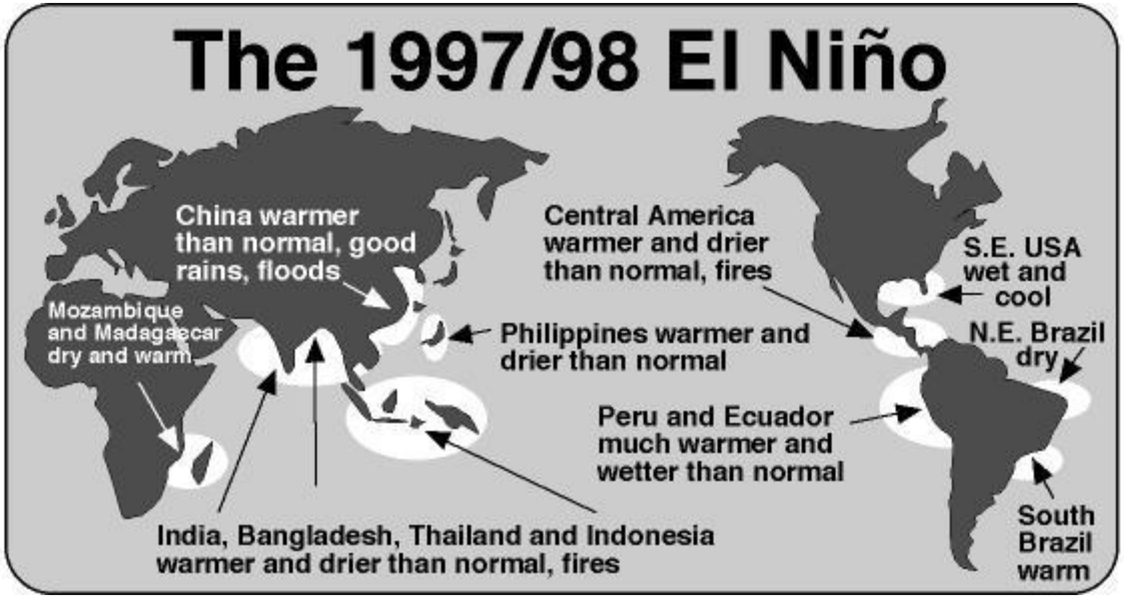
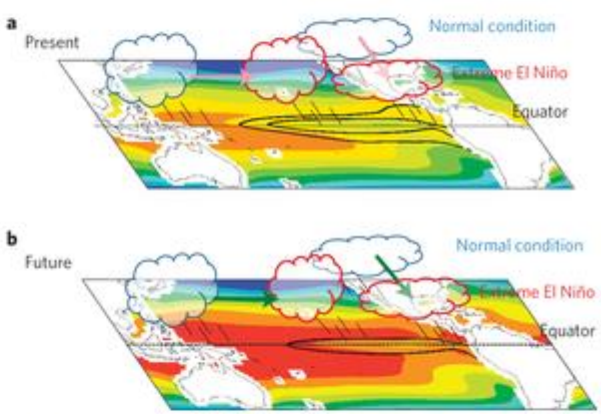


Figure 4: Schematic depicting the mechanism for increased occurrences of extreme El Niño under greenhouse warming.



a,**b**, In both present-day climate (**a**) and future climate (**b**), convection zones in the western Pacific and the ITCZ latitudes shift from their normal positions (indicated by blue clouds) to the eastern equatorial Pacific during an extrem...

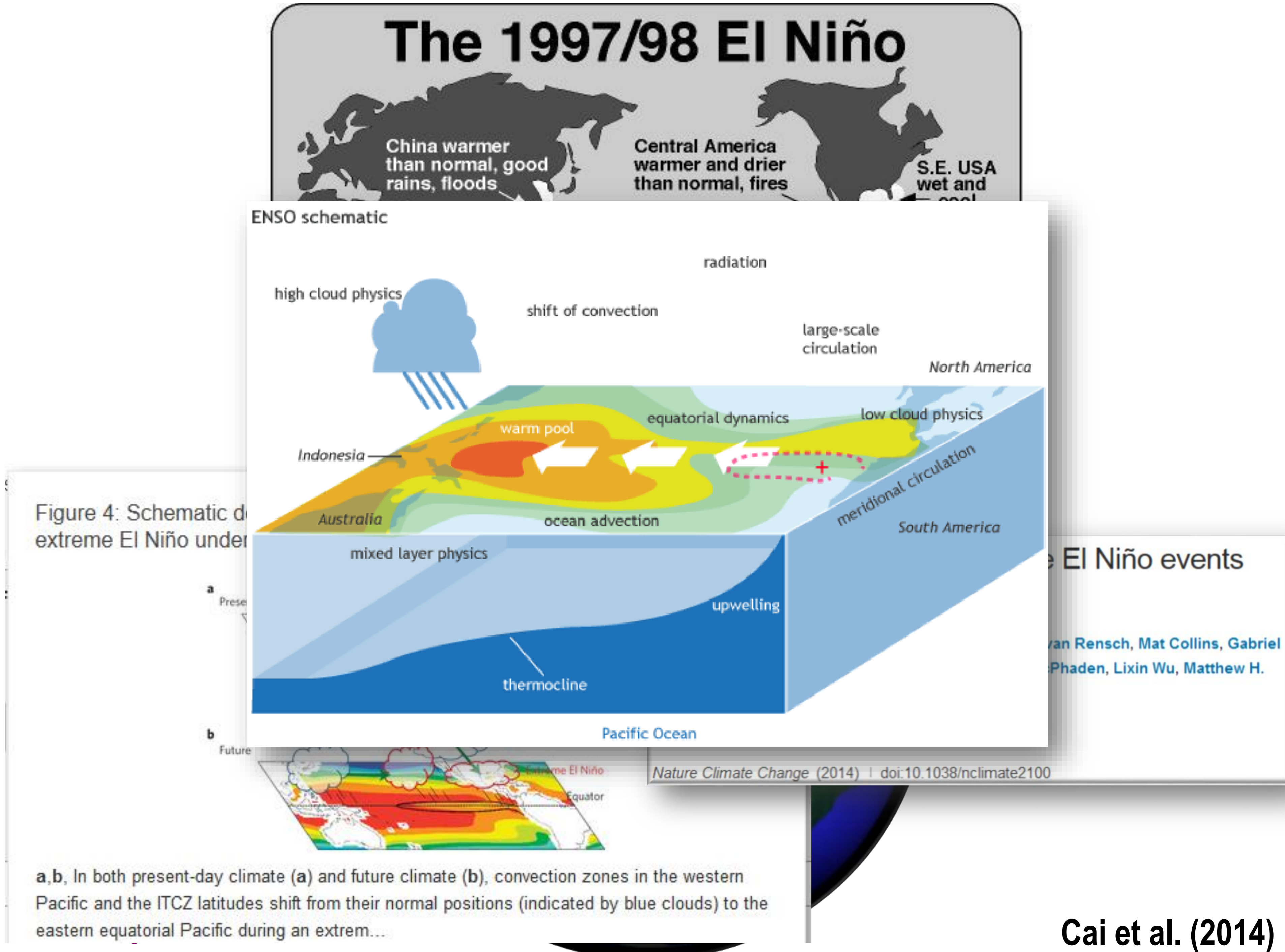
Increasing frequency of extreme El Niño events due to greenhouse warming

Wenju Cai, Simon Borlace, Matthieu Lengaigne, Peter van Rensch, Mat Collins, Gabriel Vecchi, Axel Timmermann, Agus Santoso, Michael J. McPhaden, Lixin Wu, Matthew H. England, Guojian Wang, Eric Guilyardi & Fei-Fei Jin

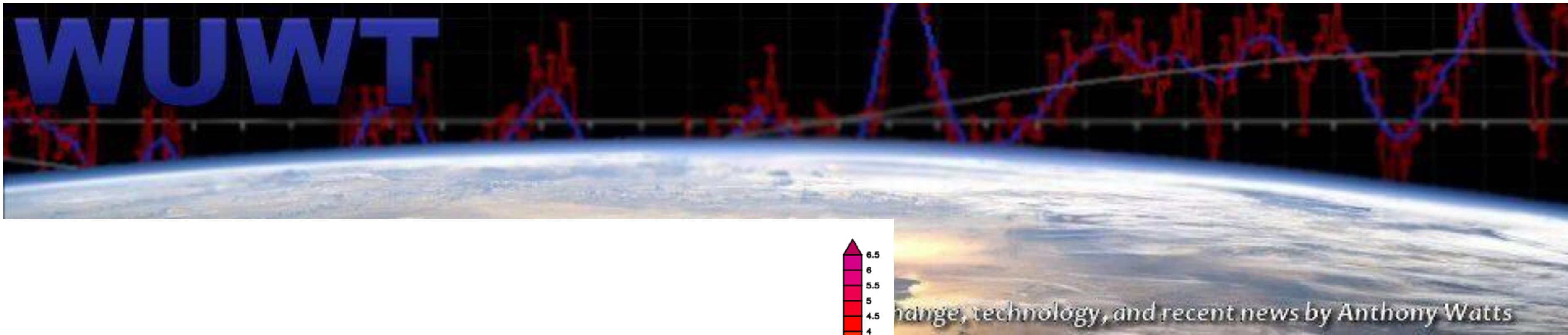
Affiliations | Contributions | Corresponding author

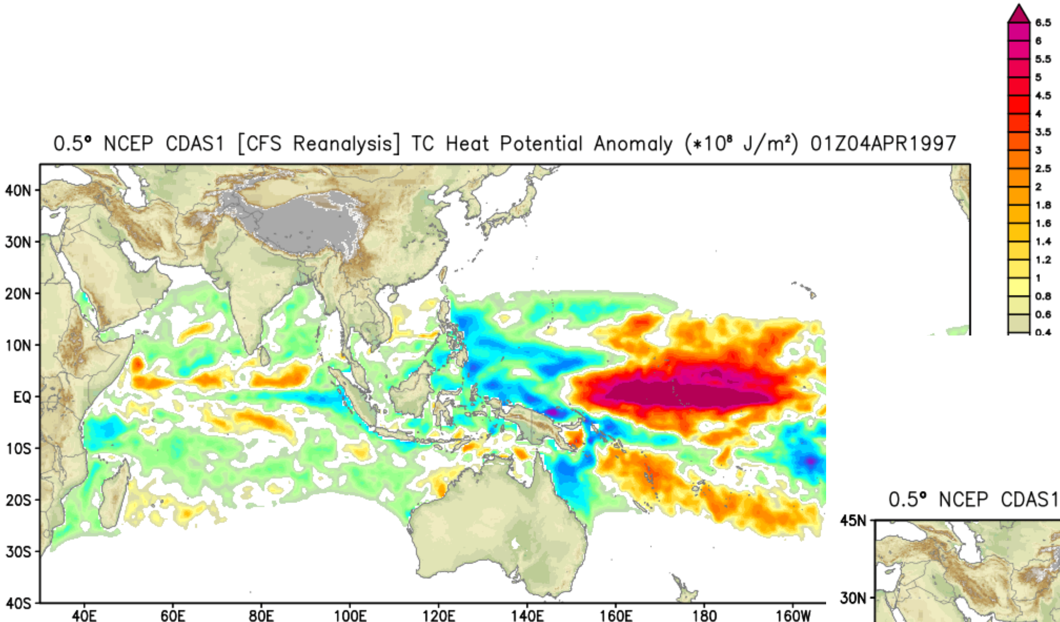
Nature Climate Change (2014) | doi:10.1038/nclimate2100

Cai et al. (2014)



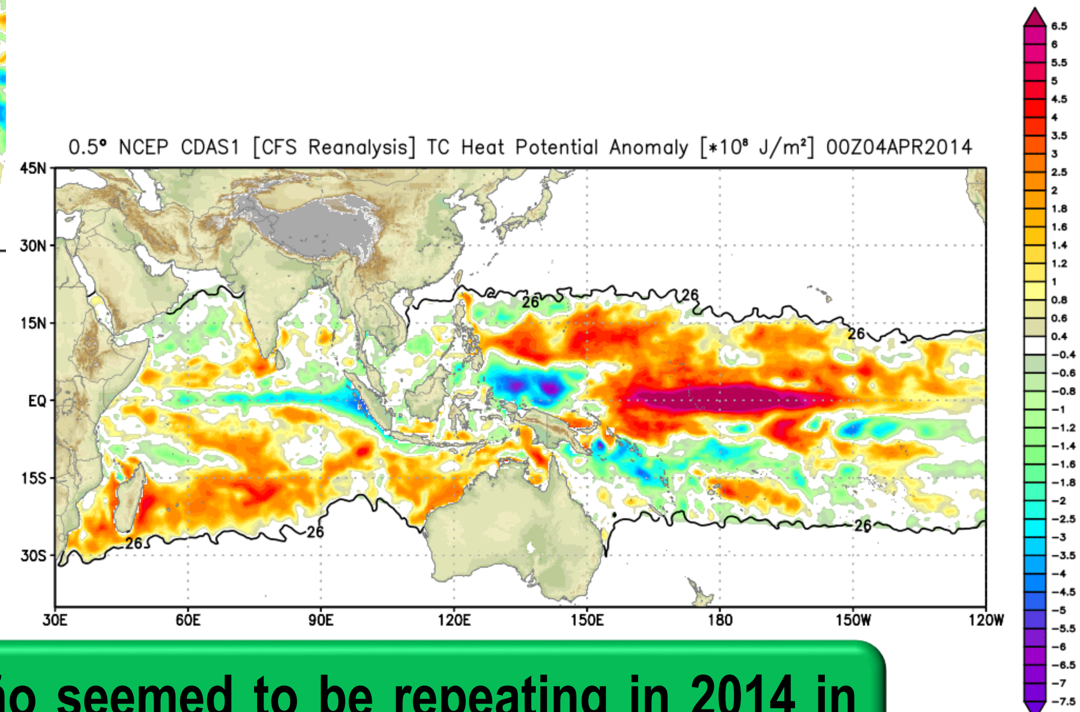
Cai et al. (2014)



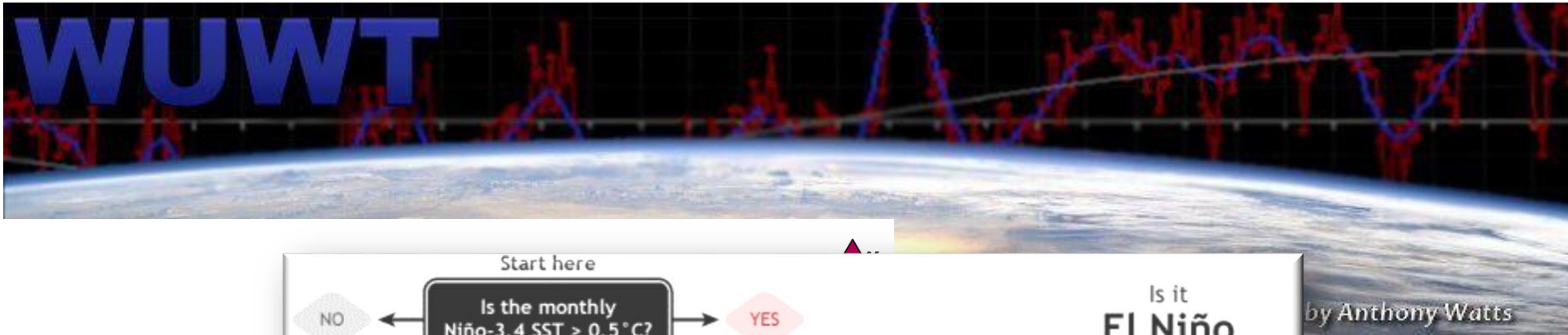


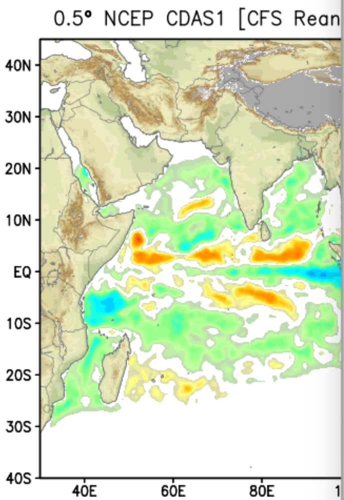
Ocean Heat content anomaly
on 4 April 1997

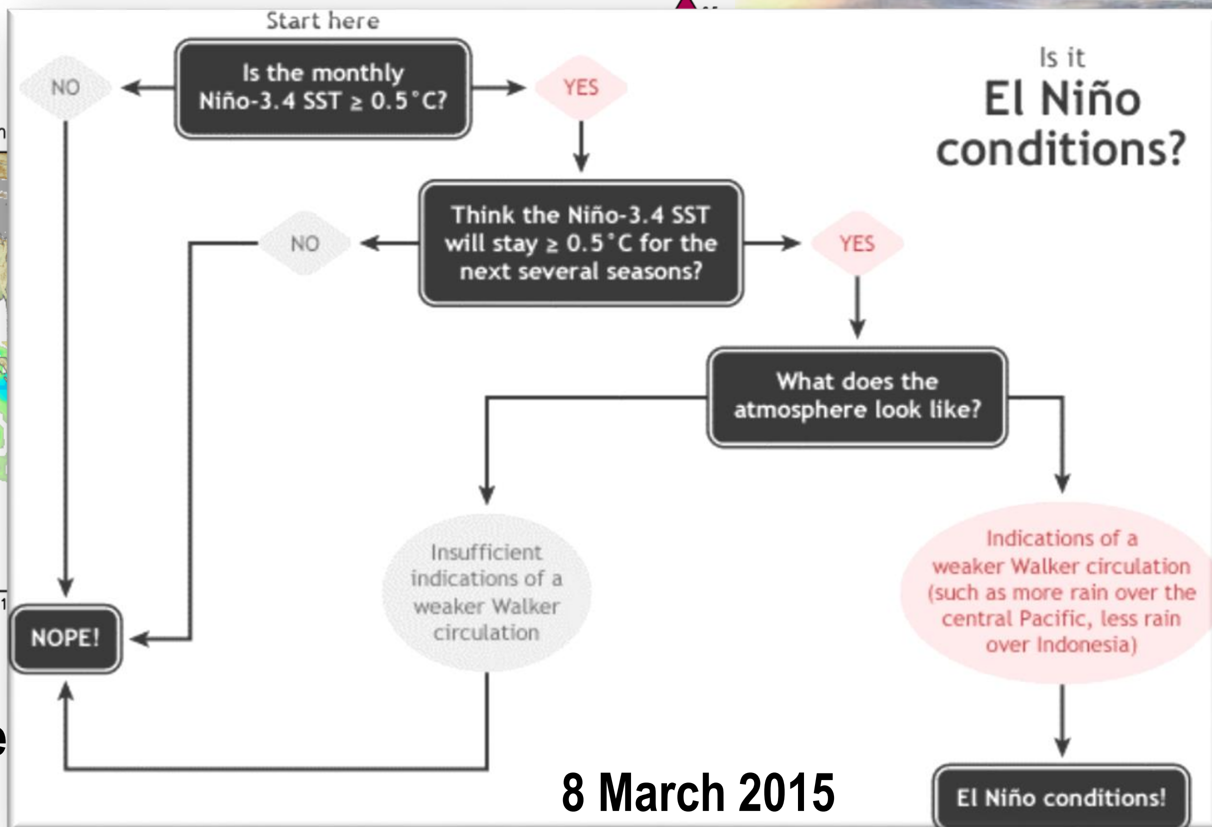
Ocean Heat content anomaly
on 4 April 2014



Elements of the 1997 Super El Niño seemed to be repeating in 2014 in the Western Pacific







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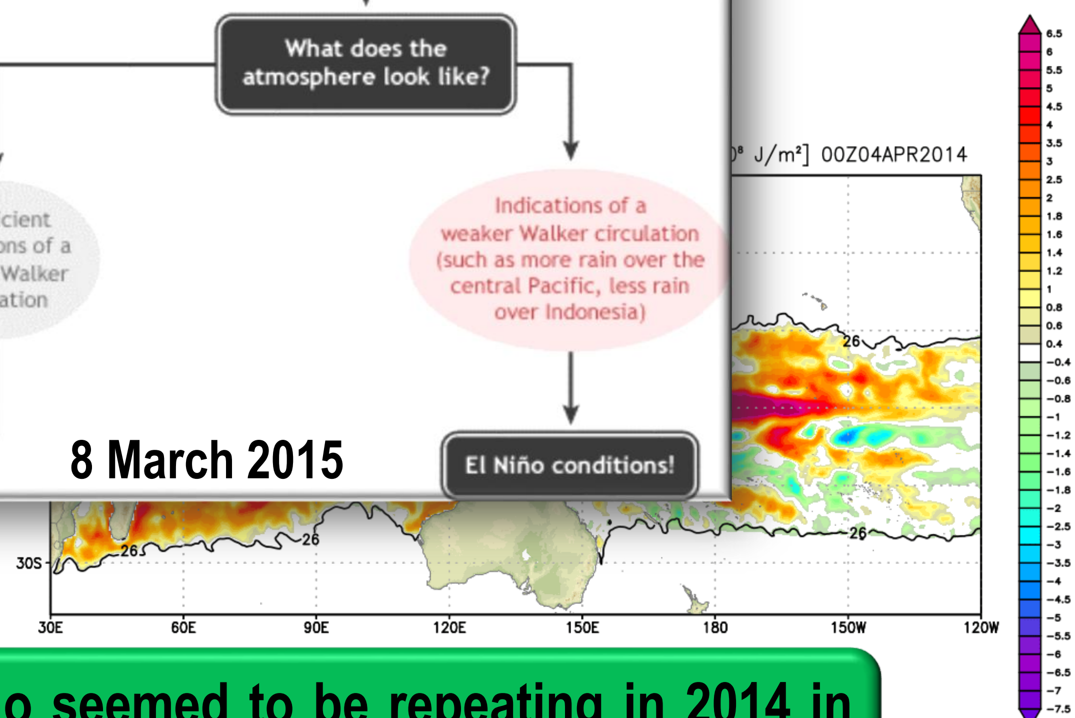
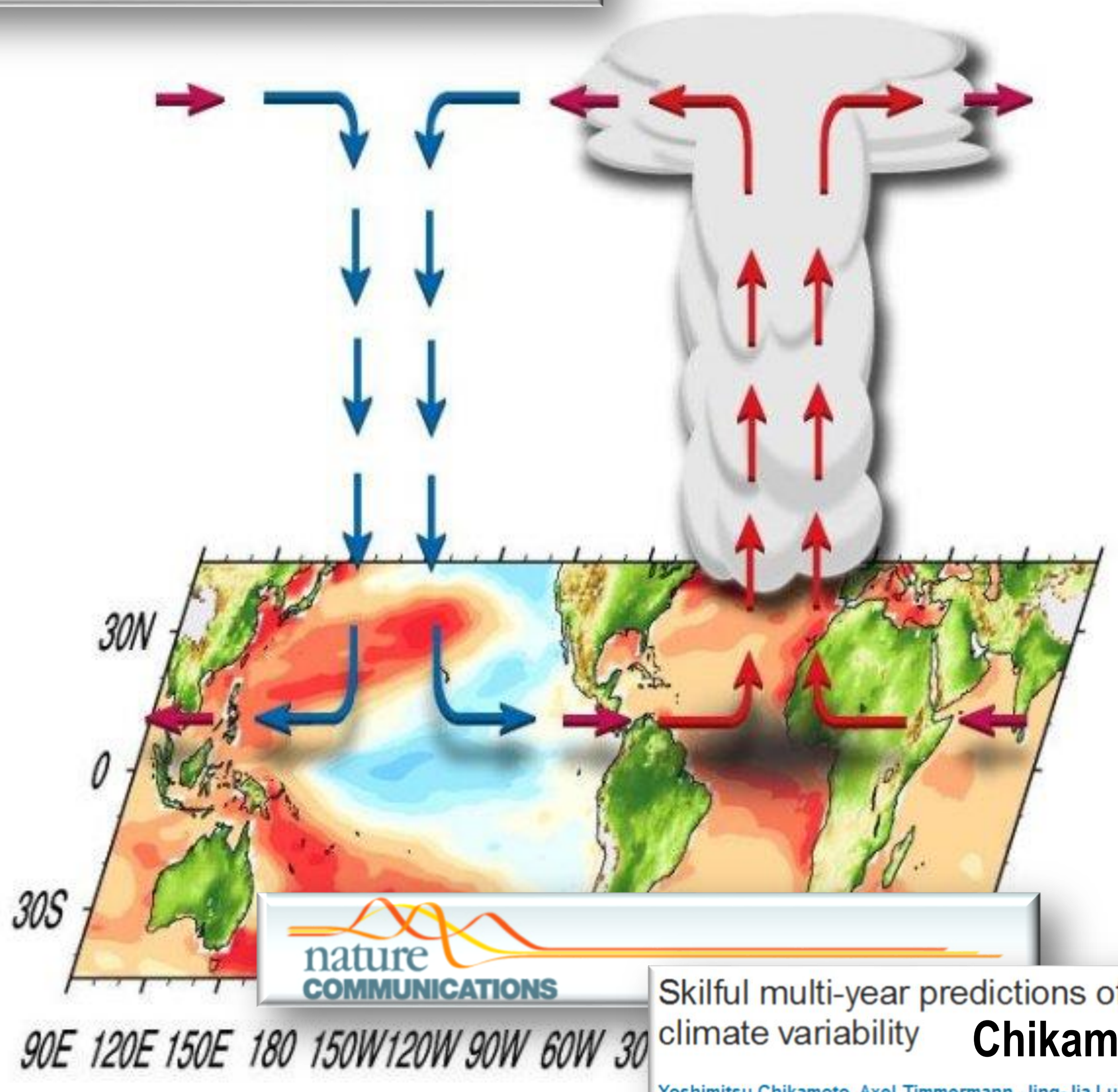


Elements of the 1997 Super El Niño seemed to be repeating in 2014 in the Western Pacific

Science News

ScienceDaily

Extending climate predictability beyond El Niño



nature COMMUNICATIONS

Skilful multi-year predictions of tropical trans-basin climate variability

Chikamoto et al. (2015)

Yoshimitsu Chikamoto, Axel Timmermann, Jing-Jia Luo, Takashi Mochizuki, Masahide Kimoto, Masahiro Watanabe, Masayoshi Ishii, Shang-Ping Xie & Fei-Fei Jin

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Science News

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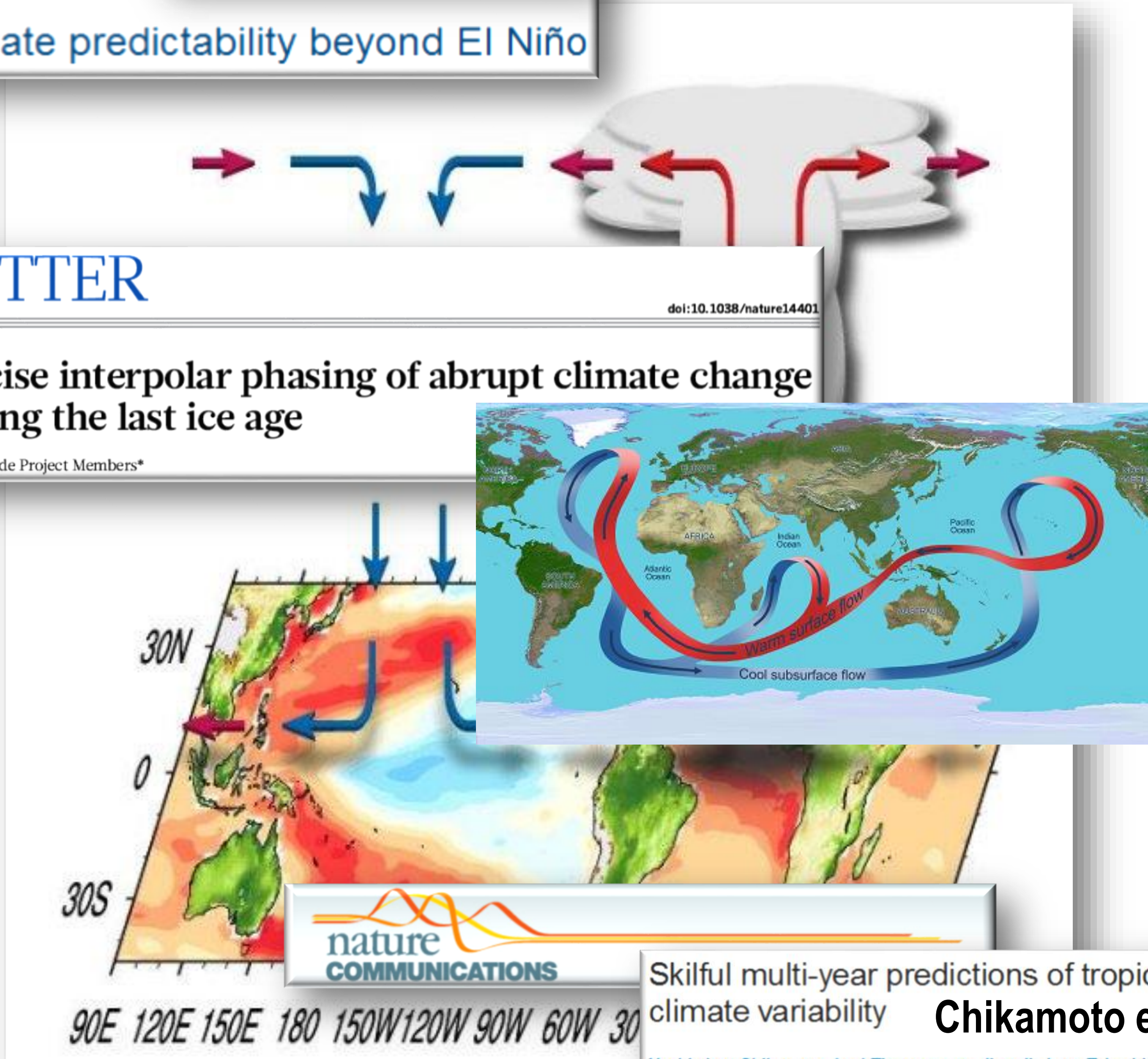

LETTER

doi:10.1038/nature14401

Precise interpolar phasing of abrupt climate change during the last ice age

WAIS Divide Project Members*

nature COMMUNICATIONS

Skilful multi-year predictions of tropical trans-basin climate variability

Chikamoto et al. (2015)

Yoshimitsu Chikamoto, Axel Timmermann, Jing-Jia Luo, Takashi Mochizuki, Masahide Kimoto, Masahiro Watanabe, Masayoshi Ishii, Shang-Ping Xie & Fei-Fei Jin

Global Ecology and Biogeography, (Global Ecol. Biogeogr.) (2013) **22**, 1261–1271

A Journal of Macroecology

RESEARCH PAPER

Large trees drive forest aboveground biomass variation in moist lowland forests across the tropics

J. W. Ferry Slik[1]*, Gary Paoli[2], Krista McGuire[3], Ieda Amaral[4], Jorcely Barroso[5], Meredith Bastian[6], Lilian Blanc[7], Frans Bongers[8], Patrick Boundja[9], Connie Clark[10], Murray Collins[11,12], Gilles Dauby[13], Yi Ding[14,15], Jean-Louis Doucet[16], Eduardo Eler[4], Leandro Ferreira[17], Olle Forshed[18], Gabriella Fredriksson[19], Jean-Francois Gillet[20], David Harris[21], Miguel Leal[22], Yves Laumonier[23], Yadvinder Malhi[24], Asyraf Mansor[25], Emanuel Martin[26], Kazuki Miyamoto[27], Alejandro Araujo-Murakami[28], Hidetoshi Nagamasu[29], Reuben Nilus[30], Oliveira[4], Onrizal Onrizal[32], Alexander Parada-Gutierrez[28], ens Poorter[8], John Poulsen[10], Hirma Ramirez-Angulo[34], Jan Reitsma[35], es Rozak[37], Douglas Sheil[38,39,40], Javier Silva-Espejo[41], Marcos Silveira[42], ter Steege[43], Tariq Stevart[44], Gilberto Enrique Navarro-Aguilar[45], Suzuki[46], Jianwei Tang[47], Ida Theilade[48], Geertje van der Heijden[49,50], Tran Van Do[52], Emilio Vilanova[53], Vincent Vos[54], Serge Wich[55], oshi Yoneda[57], Runguo Zang[58], Ming-Gang Zhang[59] and Nicole Zweifel[60]

greenreport.it

Non tagliate i vecchi alberi: assorbono la metà della CO2 delle foreste pluviali

[9 agosto 2013]

First signs of carbon sink saturation in European forest biomass

Gert-Jan Nabuurs,, Marcus Lindner,, Pieter J. Verkerk,, Katja Gunia,, Paola Deda,, Roman Michalak & & Giacomo Grassi

Affiliations Contributions Corresponding author

Nature Climate Change (2013) doi:10.1038/nclimate185

ANSA.it

Ambiente&Energia

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Foreste europee vicine a saturazione assorbimento CO2

Tra le cause invecchiamento alberi, deforestazione e incendi

20 agosto, 20:10

Global Ecology and Biogeography, (Global Ecol. Biogeogr.) (2013) **22**, 1261–1271

Macroecology

RESEARCH PAPER

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Climate extremes and the carbon cycle

Markus Reichstein, Michael Bahn, Philippe Ciais, Dorothea Frank, Miguel D. Mahecha, Sonia I. Seneviratne, Jakob Zscheischler, Christian Beer, Nina Buchmann, David C. Frank, Dario Papale, Anja Rammig, Pete Smith, Kirsten Thonicke, Marijn van der Velde, Sara Vicca, Ariane Walz & Martin Wattenbach

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Michalak & & Giacomo Grassi

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Nature Climate Change (2013) doi:10.1038/nclimate185

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ANSA > Ambiente&Energia > Clima > Foreste europee vicine a saturazione assorbimento CO2

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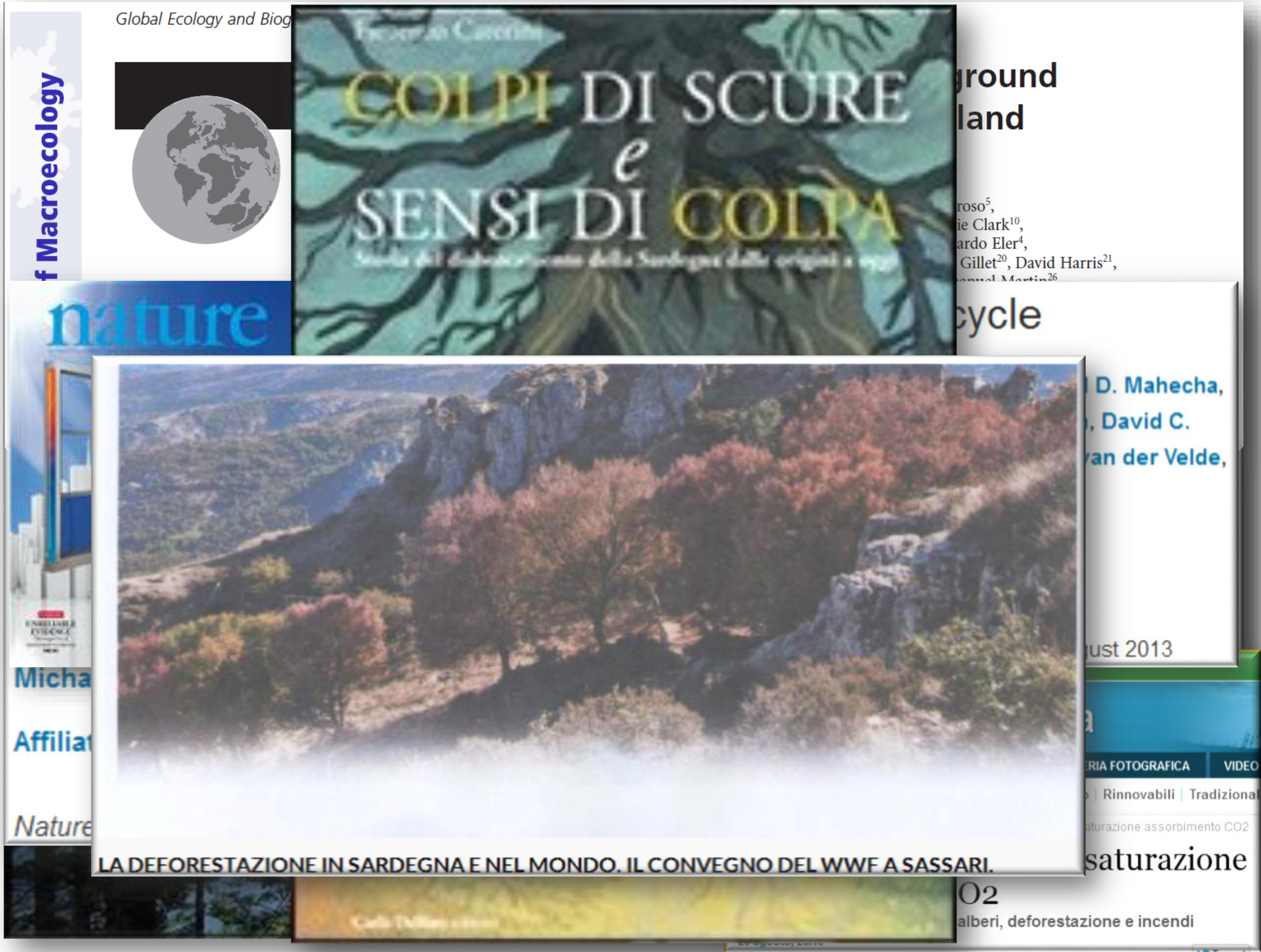
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Affiliat
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LA DEFORESTAZIONE IN SARDEGNA E NEL MONDO. IL CONVEGNO DEL WWF A SASSARI.
RIA FOTOGRAFICA
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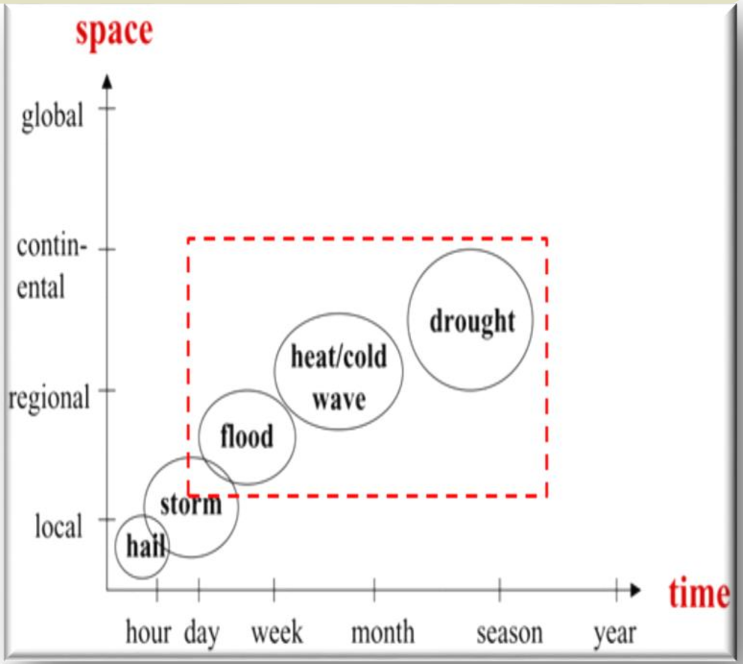
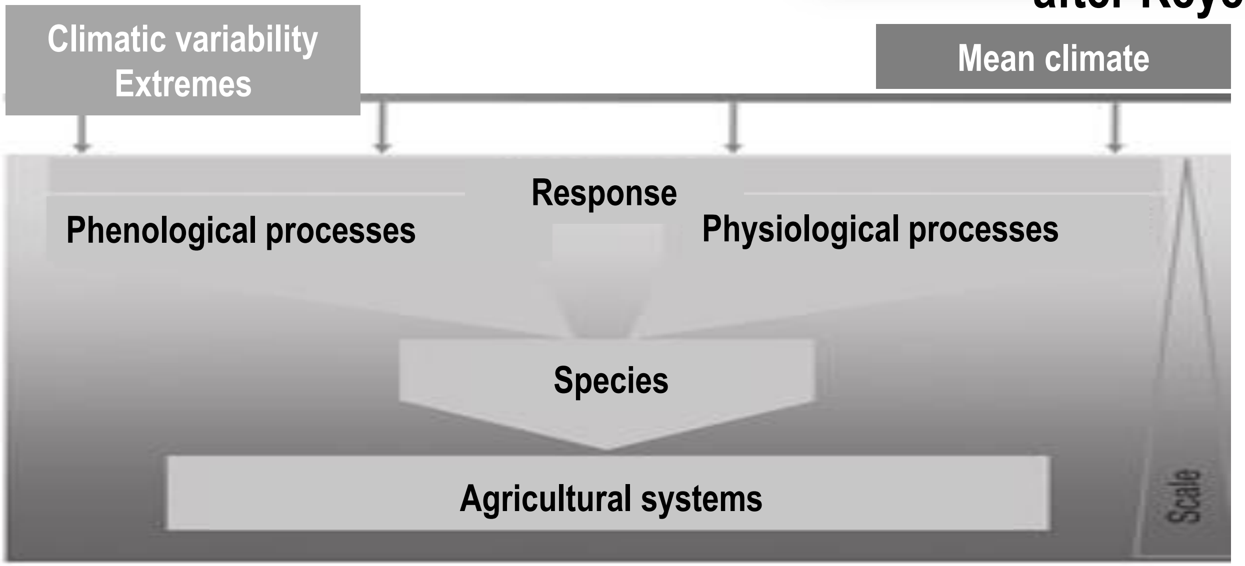
Tradizional
turazione assorbimento CO2
saturazione
O2
alberi, deforestazione e incendi

Modelling the impact of extreme events

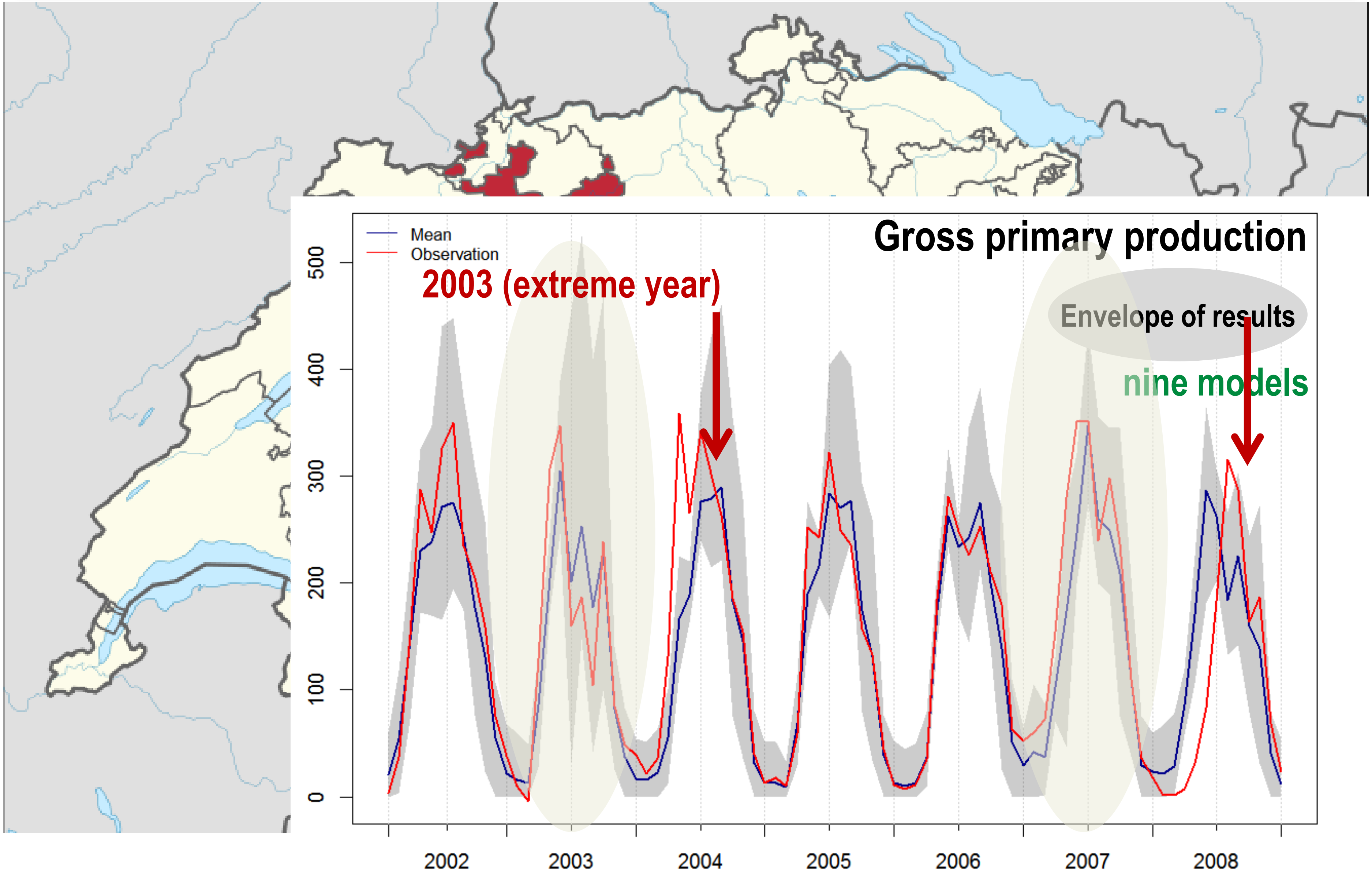
- Extreme weather events such as **heat waves**, **cold shocks**, **droughts** and **floods** are expected to increase in intensity, frequency and extension with climate change
- There is a need to better integrate the effects of extreme events into simulation (crop / grassland / tree) models to better estimate their **impact on agricultural systems**



after Reyer et al. (2013)



Ensemble modelling on grasslands



(Ma et al., 2014)

“Extreme” versus “adverse” events

20.12.2013 EN Official Journal of the European Union L 347/487

REGULATION (EU) No 1305/2013 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 17 december 2013

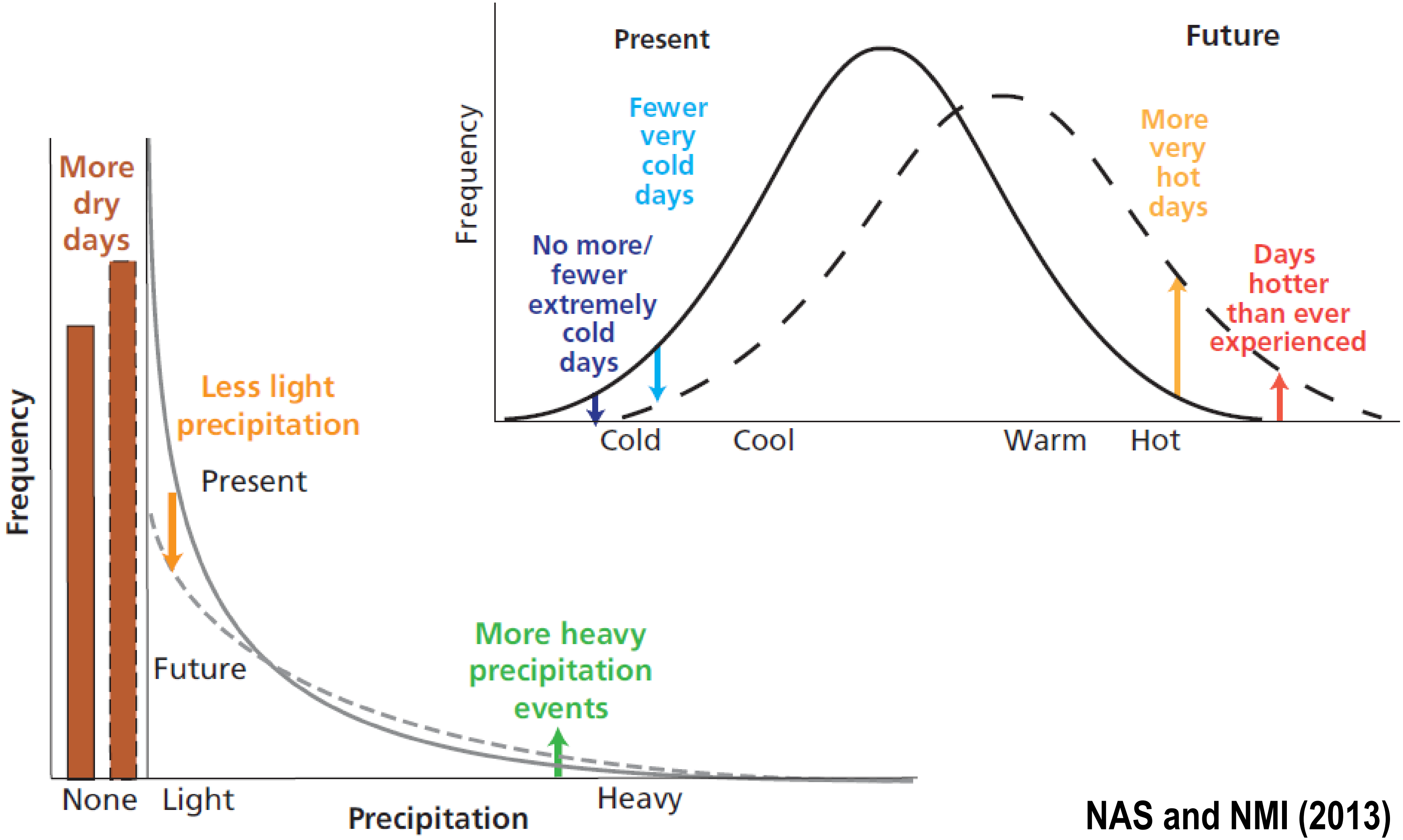
on support for rural development by the Europe... Fund for Rural Development (EAFRD) and repealing Cou... No 1698/2005

adverse climatic event:

weather conditions ... il, ice, heavy rain or severe drought, which can b... disaster

Problematic the way how extreme events are (or seem to be) assimilated to natural disasters

Extreme weather events: statistical definition



NAS and NMI (2013)

Extreme weather events: what a definition?

extreme weather event:

- (statistically-based) a rare weather event at a particular place and time of year, e.g. "*as rare or rarer than the 10th or 90th percentile of PDF*" (IPCC, 2013)

- (impact-oriented) high-impact (on society and biophysical systems), hard-to-predict phenomenon that is far beyond normal expectations, e.g. "*Agricultural drought occurs when there is insufficient moisture for average crop or range production*" (Sivakumar et al., 2005)

Extreme weather events in Europe: impacts

Year	Region	Event	Impact
2003	Western and Central Europe	Hottest summer in at least 500 years (Luterbarcher et al., 2004)	Crop harvest losses of 20-30% (Ciais et al., 2005); Mega-fires; Health damage
2004-2005	Iberian Peninsula	Hydrological drought	Grain harvest losses of 40% (EEA, 2010)
2007	Southern Europe	Hottest summer on record in Greece since 1891 (Founda and Giannakopoulos, 2009)	Mega-fires; roughly 575000 ha burnt area (JRC, 2008)
2007	England and Wales	May-July wettest since records began in 1766	78 farms flooded with about £50 million (Chatterton et al., 2010)
2010	Western Russia	Hottest summer since 1500 (Barriopedro et al., 2011)	Fire damage to forests (Shvidenko et al., 2011). Reduction in crop yields (Coumou and Rahmstorf, 2012); export ban; health damage
2011	France	Hottest and driest spring since 1880	8% decline in wheat yield (AGRESTE, 2011)

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25 JUN 2014

New study quantifies the effects of climate change in Europe

If no further action is taken and global temperature increases by 3.5°C, climate damages in the EU could amount to at least €190 billion, a net welfare loss of 1.8% of its current GDP. Several weather-related extremes could roughly double their average frequency. As a consequence, heat-related deaths could reach about 200 000.

New JRC study quantifies, among others, the costs of flood damages.

Historical drought in central-southern Italy / 1

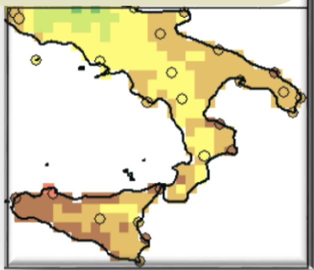
“Today, Wednesday 31st December the year 1760 is finishing, thank goodness. Food supplies have been very low because of the great drought that never seems to stop, decimating all fruits, with grapes also destined to perish, and very little must and wheat and oil (…). Drought has occurred because there has been no rain up to late December, the countryside is arid and bare of grass, and almost all the cattle are dead. Starvation threatens; much prayer is in order. God have mercy on us! Amen …” (Gregorio Susanna, Diary for 1760–1761)

“This century XVIII had a memorable and shocking year, for the fatal consequences caused by the scarcity of food and very poor harvest (…). At the beginning of this year, August 1763, drought and hail fell upon the Kingdom of Naples, causing a very poor harvest, with starvation beginning in December (…)” (chronicles of Giuseppe Loffredo)

“An overall rainy year troubles us with an obstinate and tearful drought; a year that was largely very warm punished us nevertheless with extraordinary cold and frost” (Giuseppe Maria Giovene, 1788)

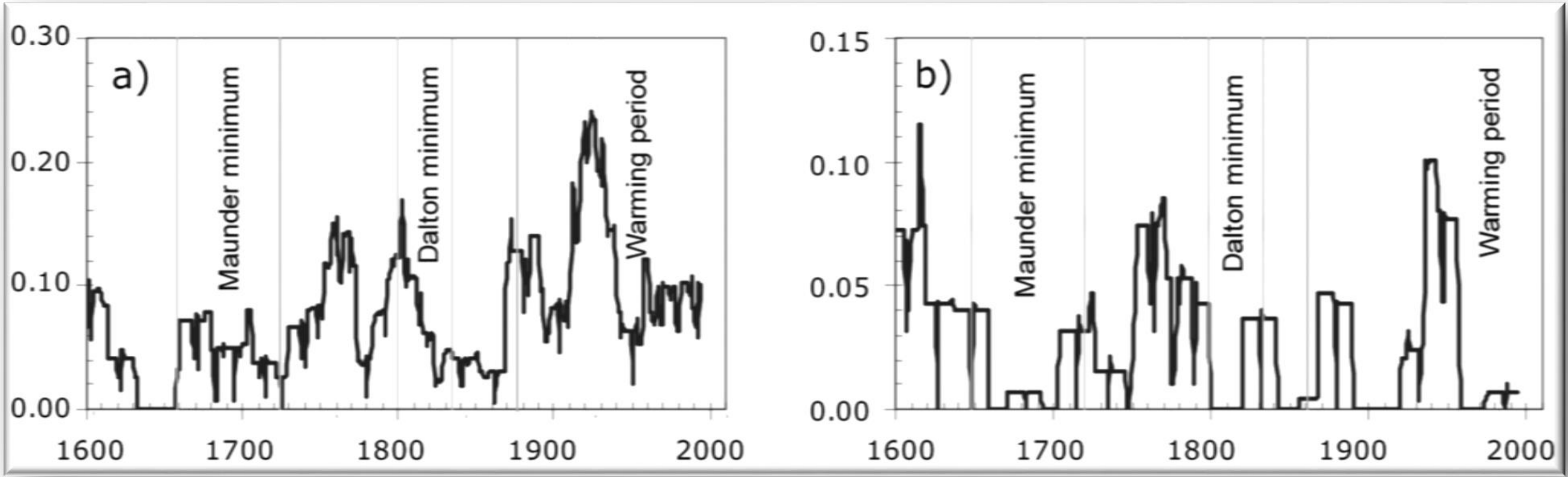
Diodato and Bellocchi (2011)

Historical drought in central-southern Italy / 2



short-term droughts
(three-five months)

prolonged droughts
(> five monthts)



Diodato and Bellocchi (2011)

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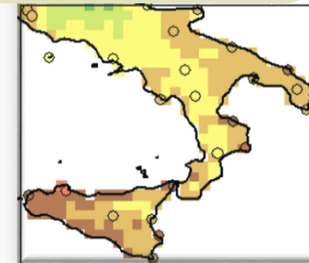

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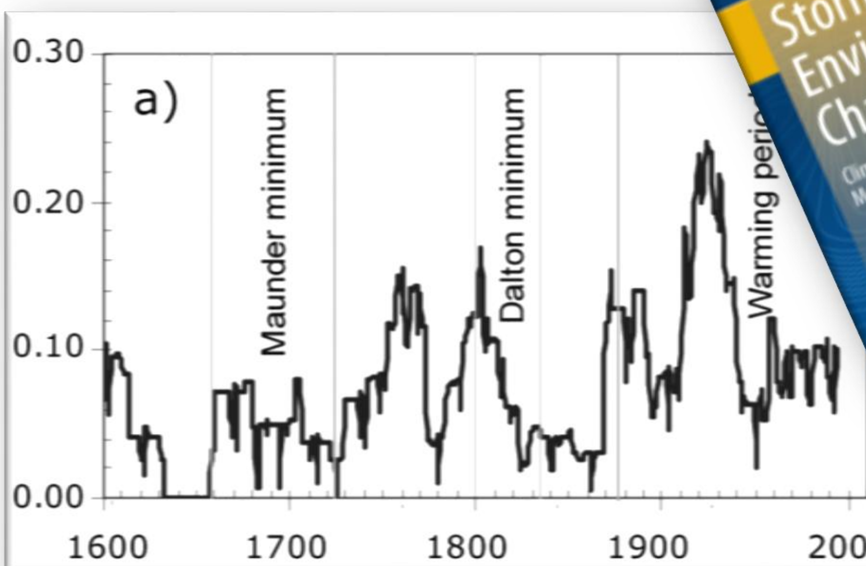
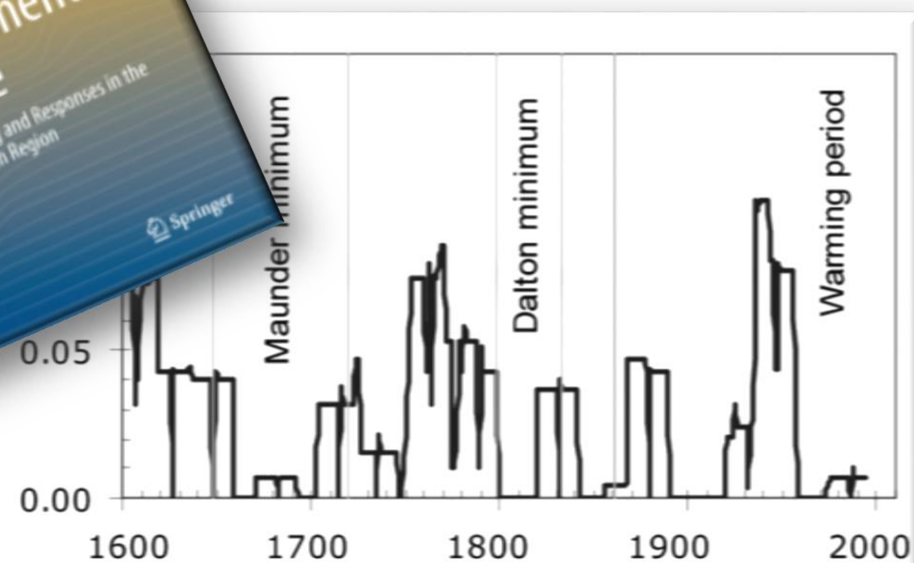
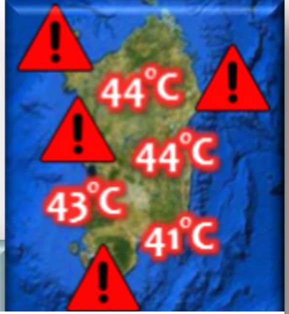




Diodato and Bellocchi (2014)

Diodato and Bellocchi (2011)

May 2015: Sardinia abnormal heatwave

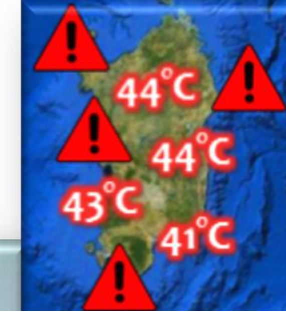


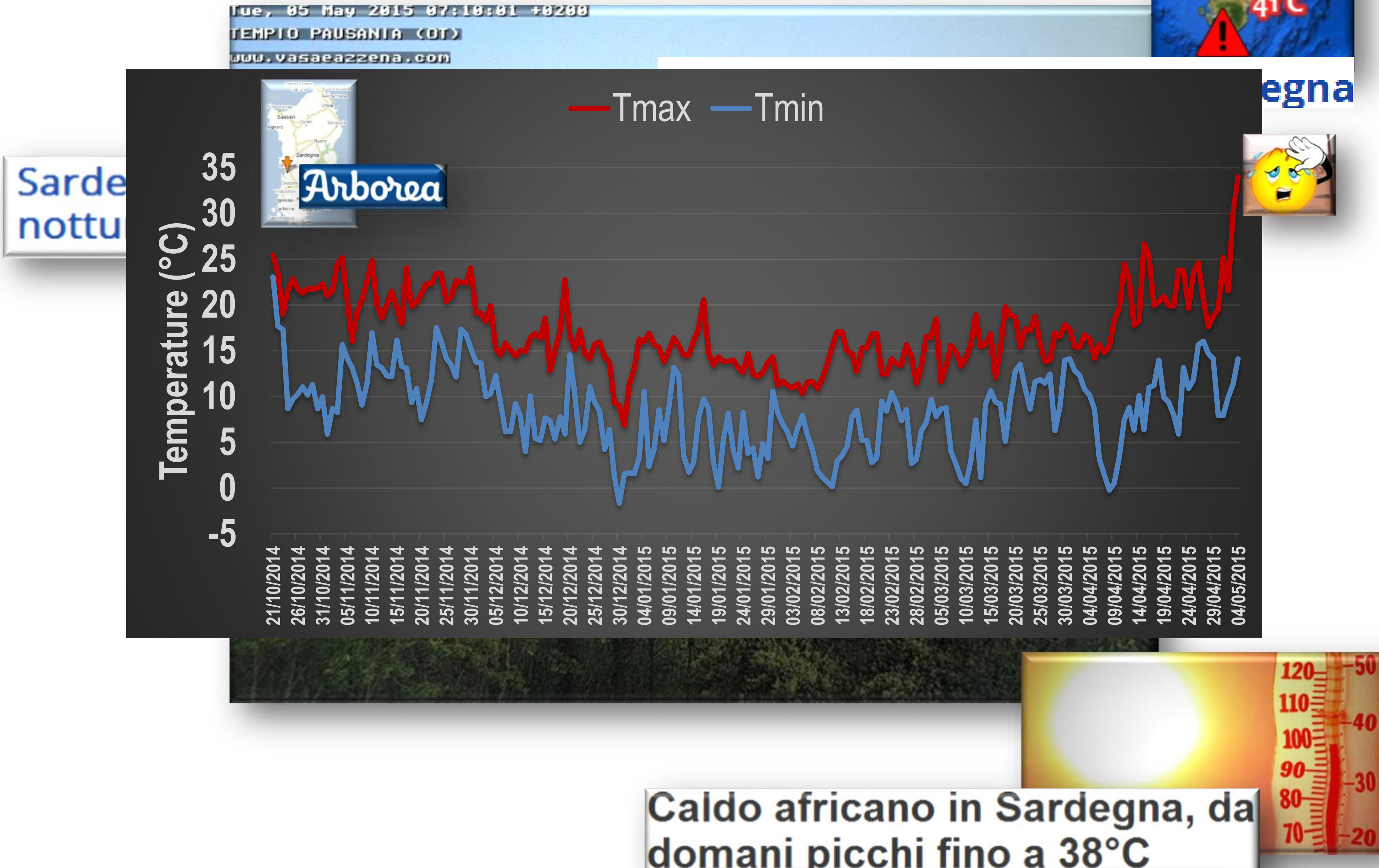
Ondata di caldo record in Sardegna

Sardegna: è storia! Picchi di TRENTA GRADI notturni. Oggi attesi anche oltre 40°C

Caldo africano in Sardegna, da domani picchi fino a 38°C

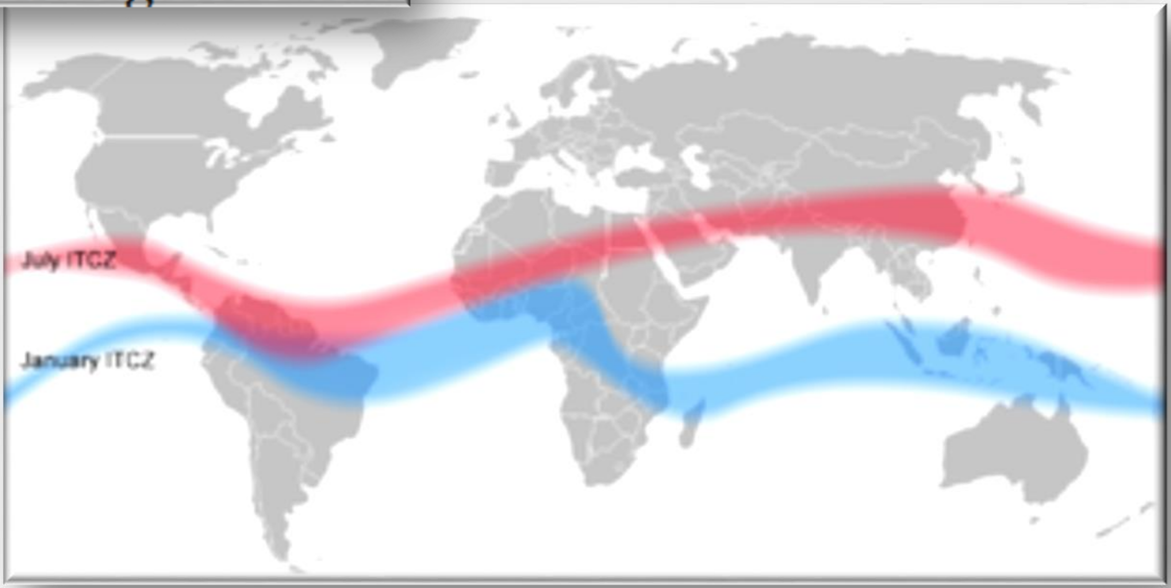
May 2015: Sardinia abnormal heatwave



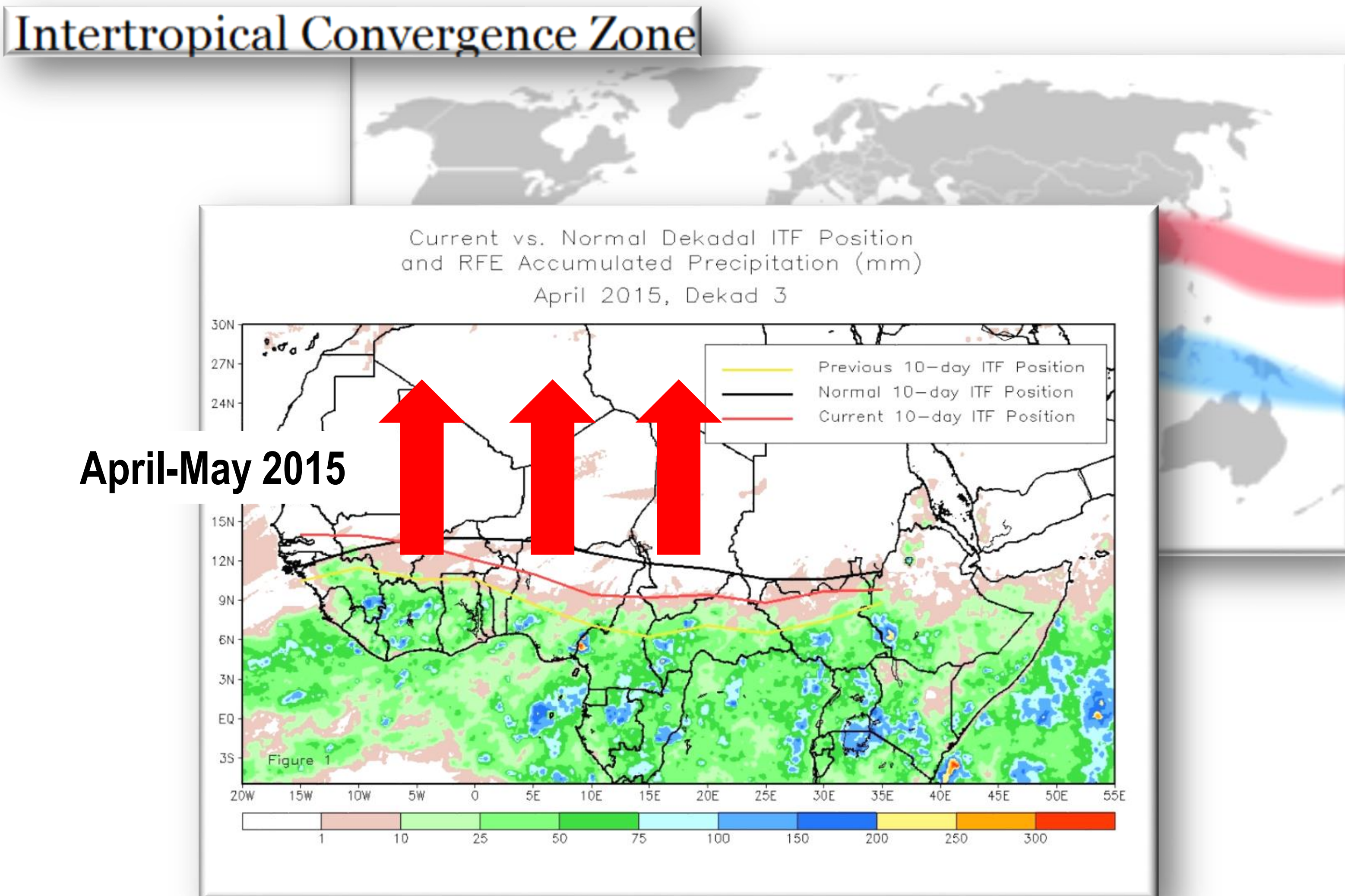


Atmospheric circulation features

Intertropical Convergence Zone

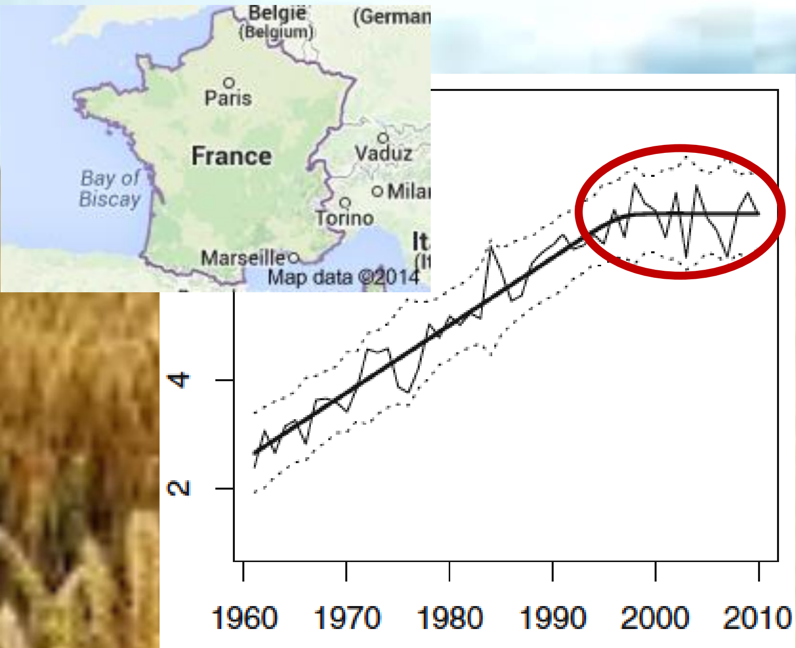


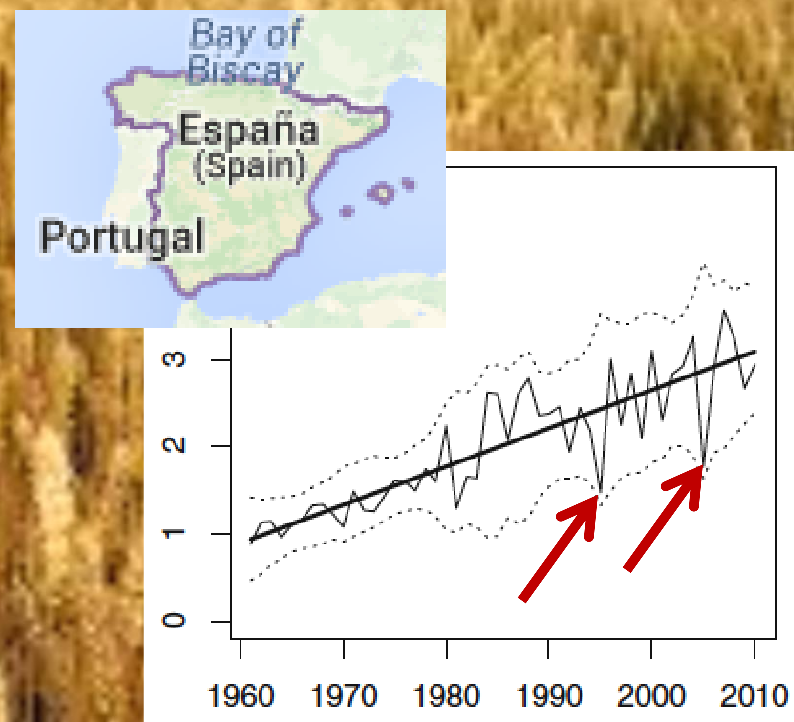
Atmospheric circulation features



Extreme weather events: agricultural impacts (winter wheat yield)

Makowski et al. (2014)





Extreme event indices: drought

$$ARID = 1 - \frac{T_a}{T_p}$$

[0, 1] Woli et al. (2012)

T_a: actual transpiration; T_p: potential transpiration

Probability of leaf growth inhibition (LGI) = Probability of ARID > threshold_{LGI}

Probability of root growth inhibition (RGI) = Probability of ARID > threshold_{RGI}

$$FU = -\frac{\sum P}{\sum ET_0} + \left[1 + \left(\frac{\sum P}{\sum ET_0}\right)^w\right]^{(1/w)}$$

[0, 1] Fu et al. (1981) Zhang et al. (2008)

P: precipitation; ET_0: reference evapotranspiration; w: vegetation-soil parameter (~3)

Extreme event indices: heat

$$HSI = \begin{cases} 1 & \text{if } T_{eff} \geq T_{lim} \\ \dfrac{T_{eff} - T_{cr}}{T_{lim} - T_{cr}} & \text{if } T_{cr} \leq T_{eff} < T_{lim} \\ 0 & \text{if } T_{eff} < T_{cr} \end{cases}$$

[0, 1]

Deryng et al. (2014)

T_{eff}: effective temperature; T_{cr}: critical temperature; T_{lim}: limiting temperature

Probability of hot days = Probability of T_{max} > T_{cr}

T_{max}: maximum temperature

Snyder and de Melo-Abreu (2005)

Extreme event indices: frost

Probability of frost damage at germination = Probability of $T_{min} < T_{frost,germ}$

Probability of frost damage at anthesis/grain filling = Probability of $T_{min} < T_{frost,anth}$

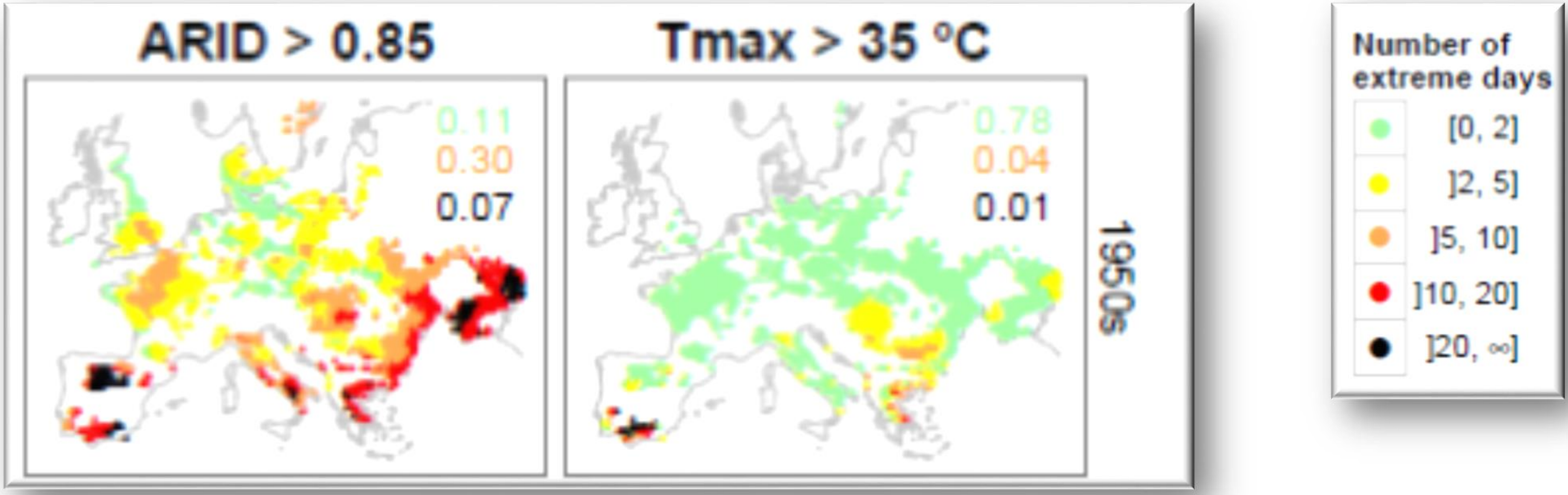
Probability of lethal frost during the growing season = Probability of $T_{min} < T_{lethal\_frost}$

T_{min}: minimum temperature
$T_{frost,germ}$: temperature of frost damage at germination
$T_{frost,anth}$: temperature of frost damage at anthesis/grin filling
T_{lethal_frost}: temperature of lethal frost during the growing season

Extreme event indices: thresholds

Index	Stage	Crop	
		maize	winter wheat
ARID - threshold$_{LGI}$	anthesis	0.20	0.10
ARID - threshold$_{RGI}$	anthesis	0.45	0.50
ARID - extreme	-	0.85	
T_{cr} (°C)	anthesis	32	25
T_{lim} (°C)	anthesis	45	35
$T_{frost,germ}$ (°C)	germination	-7	-9
$T_{anthesis,grain\ filling}$ (°C)	anthesis/grain filling	-1	
T_{lethal_frost} (°C)	growing season	-15	-20

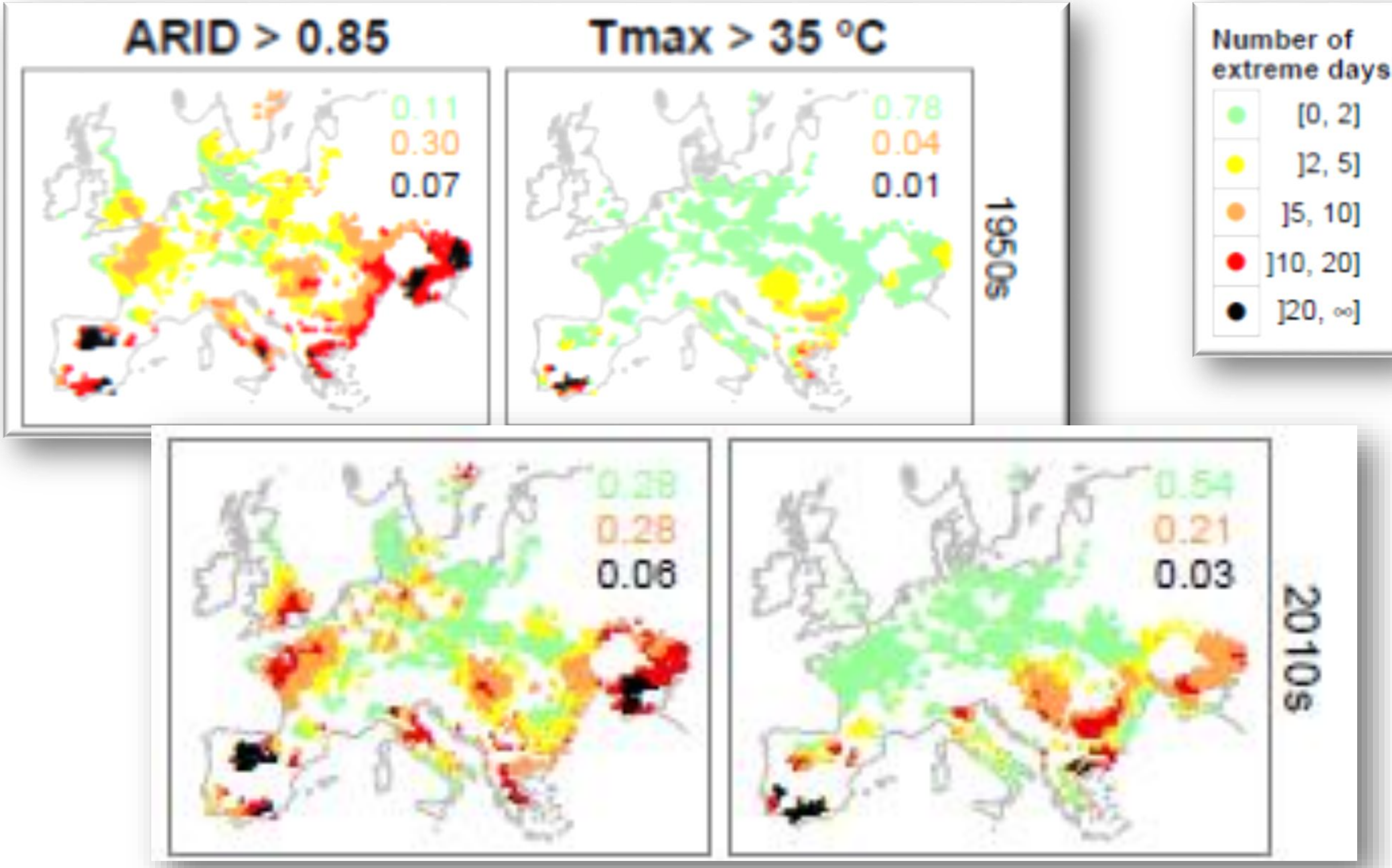
Extremely hot and dry days in Europe / 1



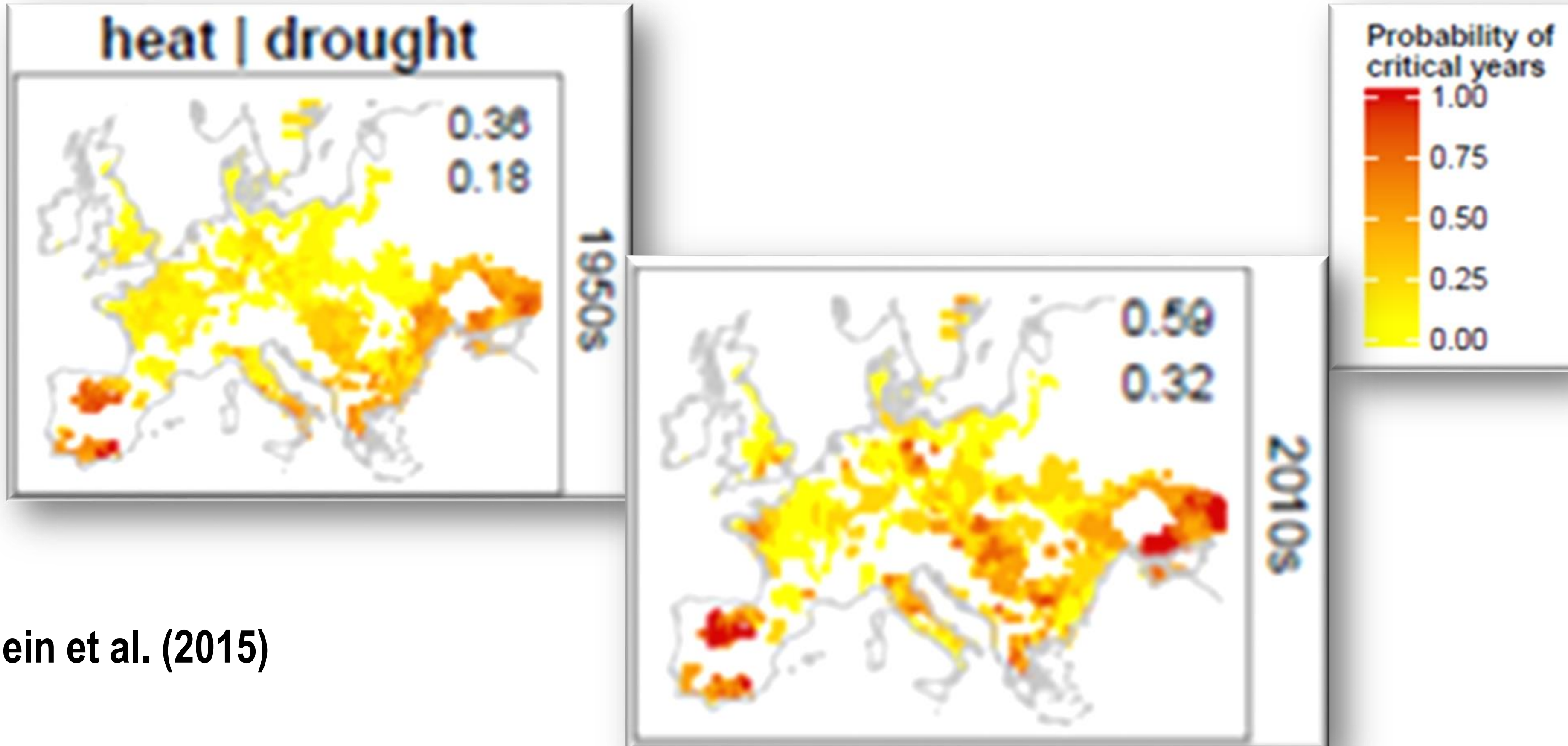
Number of extremely hot (maximum air temperature > 35 °C) and dry (ARID > 0.85) days and fraction of total winter wheat growing area of Europe with less than 2, between 5 and 10, or more than 20 extreme days per year (May 1 – September 30)

Klein et al. (in preparation)

Extremely hot and dry days in Europe / 1



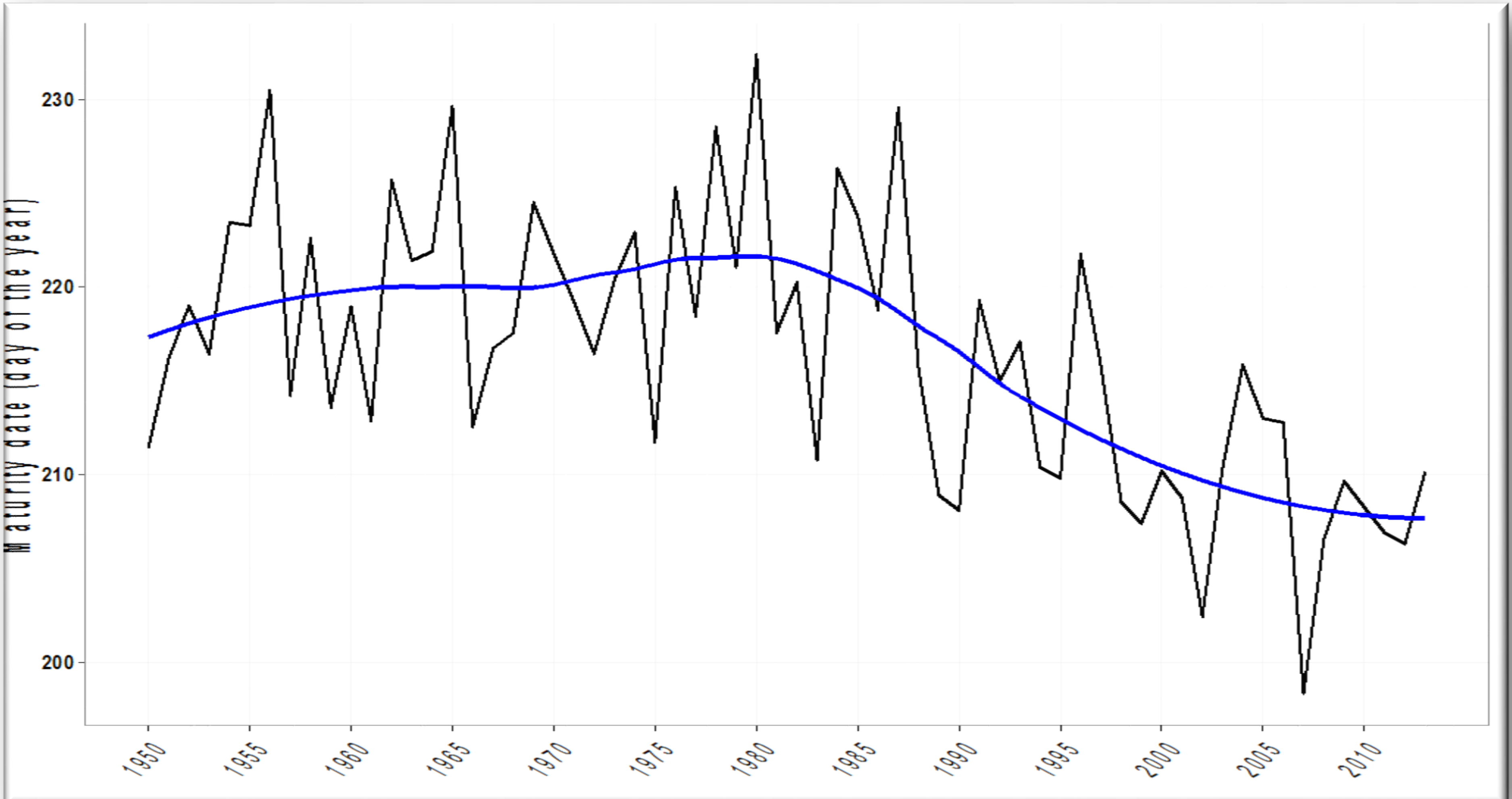
Extremely hot and dry days in Europe / 2



Klein et al. (2015)

Probability of experiencing a critical year (colour scale) and fraction of total European wheat cropping area with at least 25% and 50% chances of being under critical conditions (numbers in the upper right corner)

Extremely hot and dry days in Europe / 3

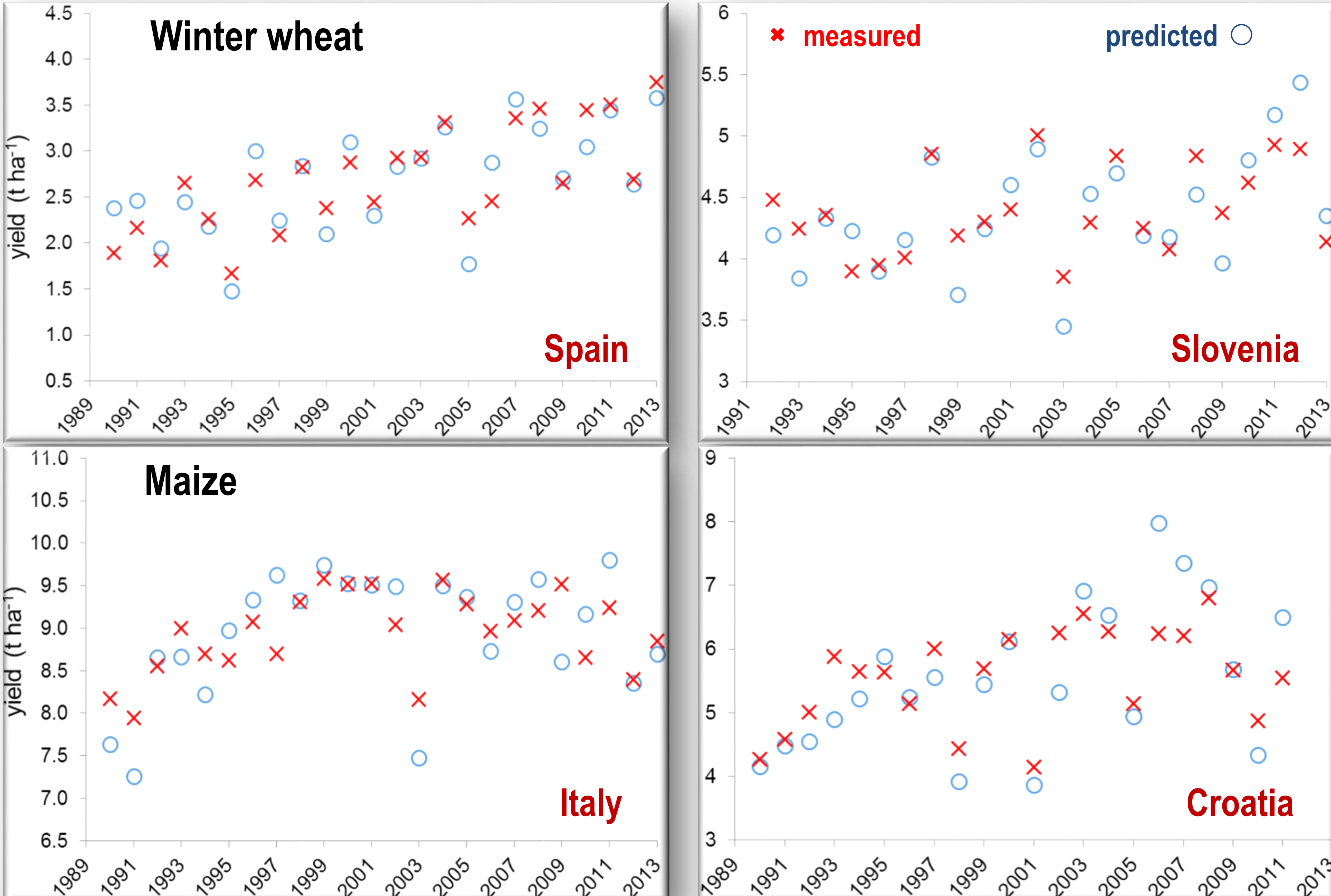


Klein et al. (in preparation)

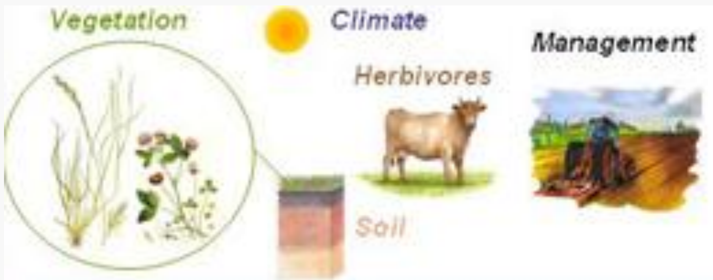
Yield forecasts with agro-climatic indices / 1

	Crop	Country	Regression model
Winter crops	Wheat	Spain	$ARID_{mean}$, $ARID_{cr}$, T_{maxcr}
		Slovenia	$ARID_{mean}$, $ARID_{cr}$, Fu, T_{mincr}
	Barley	Italy	$ARID_{cr}$, Fu, $T_{maxcr,}$ T_{mincr}
		Spain	$ARID_{cr}$, T_{maxcr}
	Rye	Spain	$ARID_{cr}$, $T_{maxcr,}$ T_{mincr}
	Triticale	Romania	$ARID_{cr}$, Fu, T_{maxcr}
	Rapeseed	Romania	$ARID_{mean}$, T_{maxcr}
Summer crops	Maize	Italy	$ARID_{mean}$, $T_{maxcr,}$ T_{mincr}
		Croatia	$ARID_{mean}$, T_{maxcr}
	Sunflower	Bulgaria	$ARID_{mean}$, Fu, T_{maxcr}
		Italy	$T_{maxcr,}$ T_{mincr}
	Potato	Romania	$ARID_{cr}$, Fu, T_{maxcr}
		Poland	$ARID_{mean}$, $ARID_{cr}$, T_{maxcr}
	Sugar beet	Italy	$ARID_{cr}$, T_{mincr}
		Croatia	$ARID_{cr}$, Fu
	Mown grasslands	Germany	$ARID_{mean}$, $ARID_{cr}$, T_{mincr}

Yield forecasts with agro-climatic indices / 2



Biophysical modelling



Agro-ecosystem

Plot scale

Modelling

Inputs
(climate, soil, management)

Initial values

Parameters

PaSim

STICS

flooding

AQUACROP

heat stress on pollination

CropSyst

cold shock on flowering

WOFOST

WARM

Grassland model

generic

specific (rice)

Crop models

implicit account of extreme events

Outputs
(yield, aboveground biomass, flowering date, …)

Biophysical processes: example of Harvest Index (HI) / 1

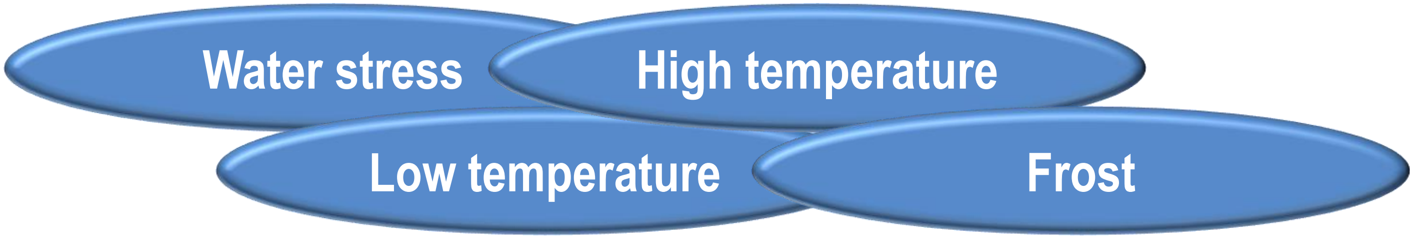
Harvest Index (HI) = yield (Y) / total above ground biomass (B)

$Y = HI \cdot B$

Valid for all crop models
(when linked to biomass at maturity)

Valid for all weather events
(drought – low temperature – high temperature)

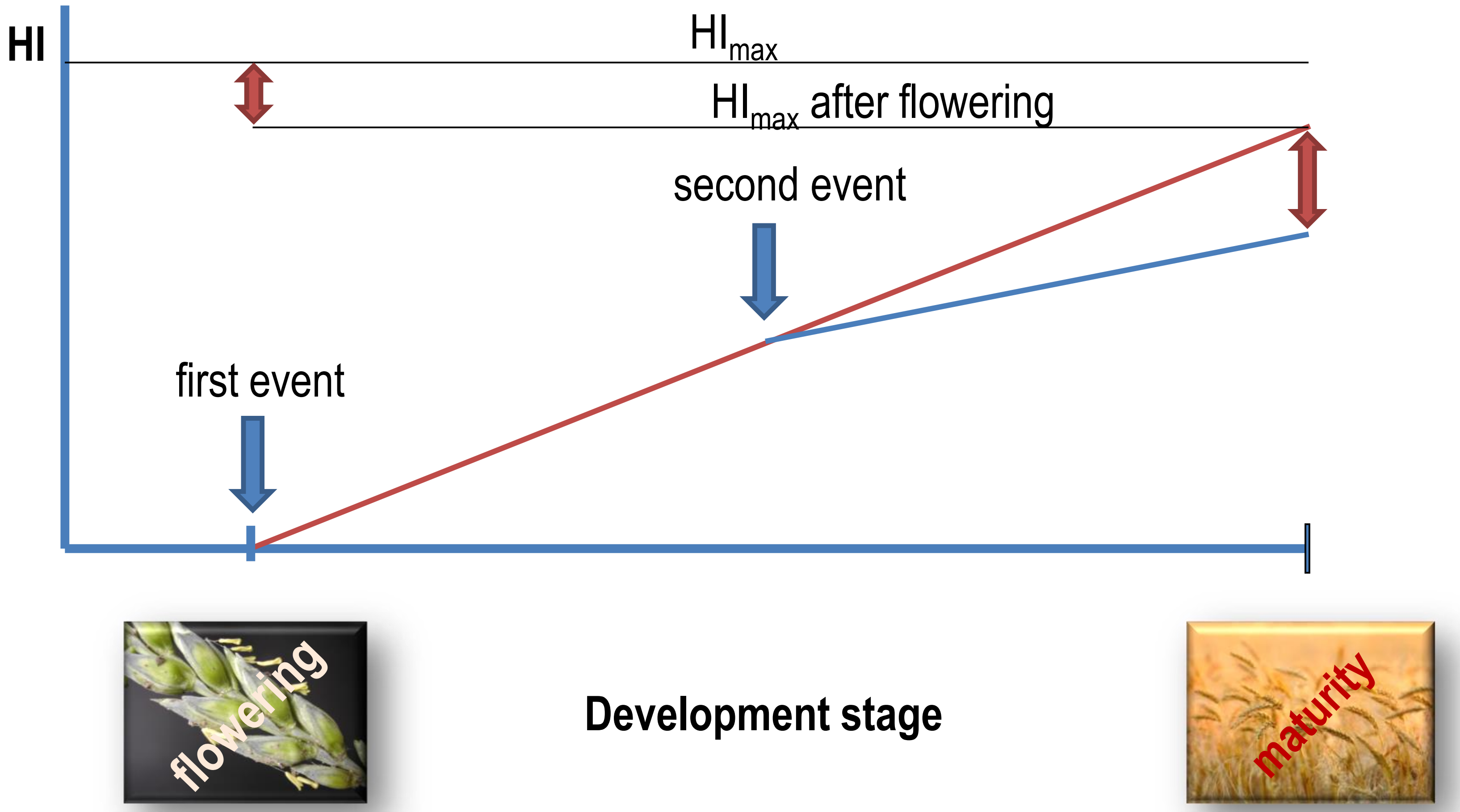
$$HI = HI_{max} \cdot f(WS) \cdot f(LT) \cdot f(HT) \cdot f(F)$$



Biophysical processes: example of Harvest Index (HI) / 2

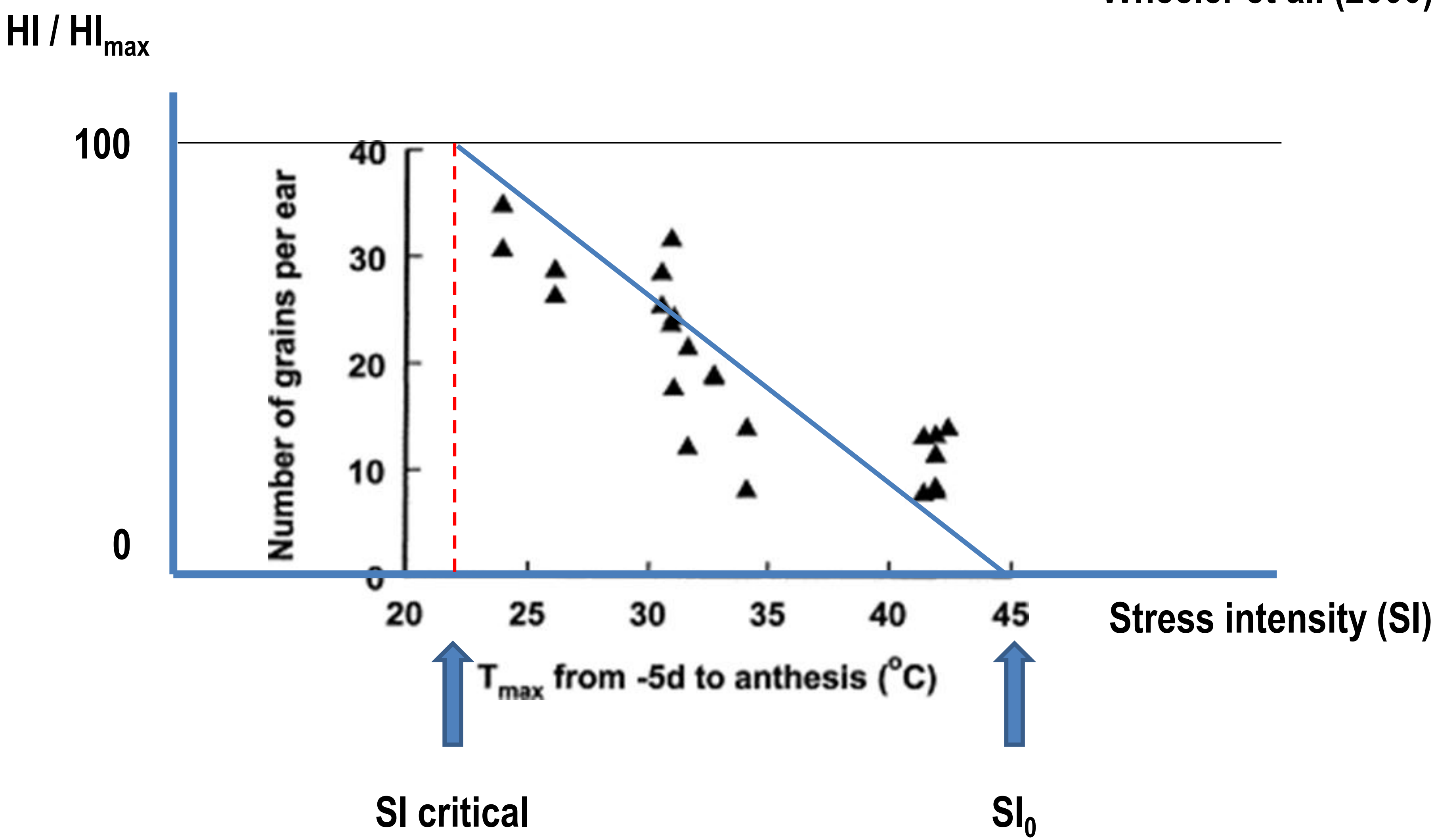
crop	pre-flowering	flowering	grain filling
winter cereals		F - WS - LT - HT	HT - WS
summer cereals		WS - LT - HT	HT - WS
sunflower	F	WS - HT	HT - WS
others	...	...	...

HI-based framework for calculating crop yield under extreme events / 1



HI-based framework for calculating crop yield under extreme events / 2

Wheeler et al. (2000)



HI-based framework for calculating crop yield under extreme events / 3

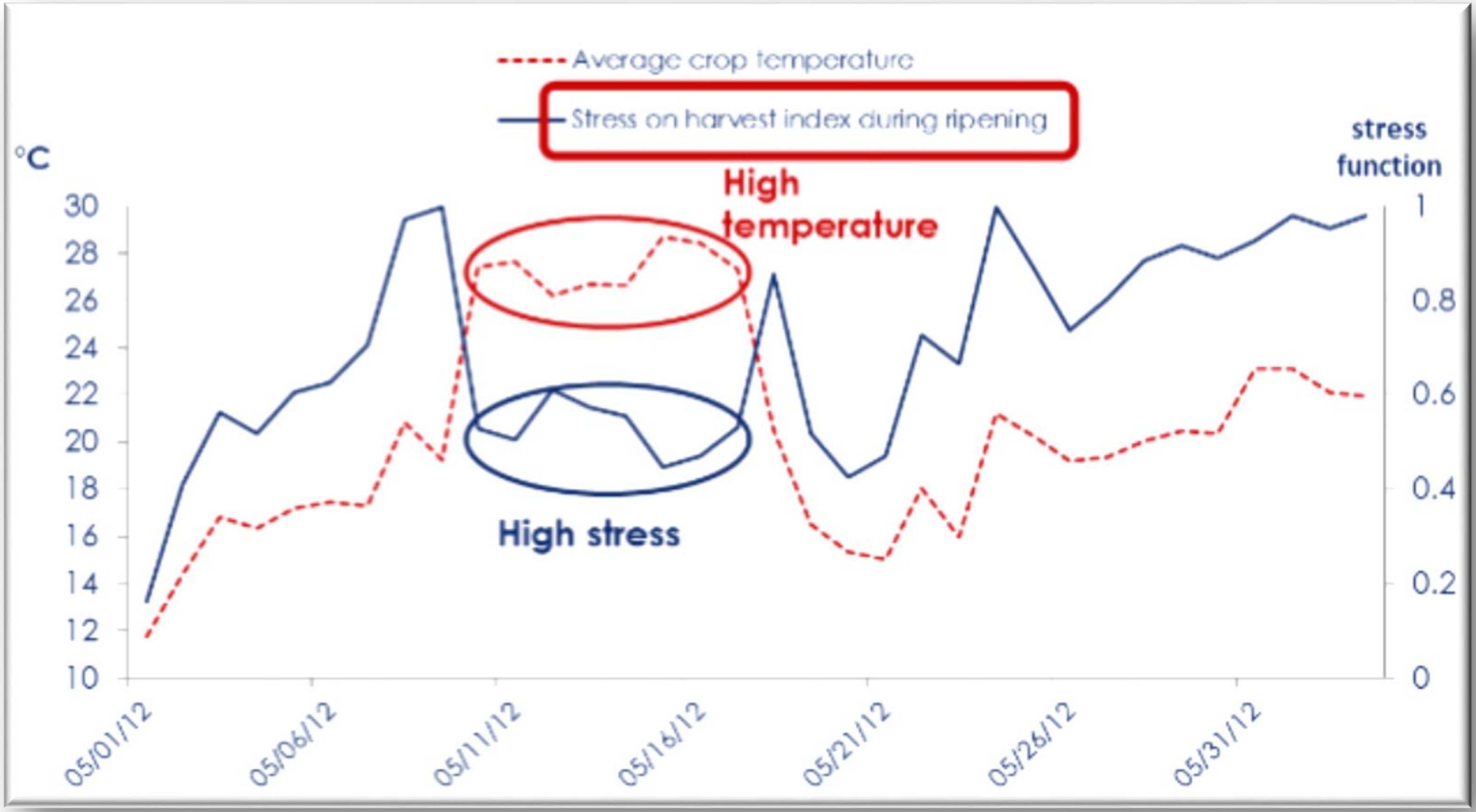
$$HI_{AA} = F_A \cdot HI_{max}$$

F_A: fraction of maximum HI that may be attained after anthesis is completed (HI_{AA})
(0, maximum stress; 1, no stress)

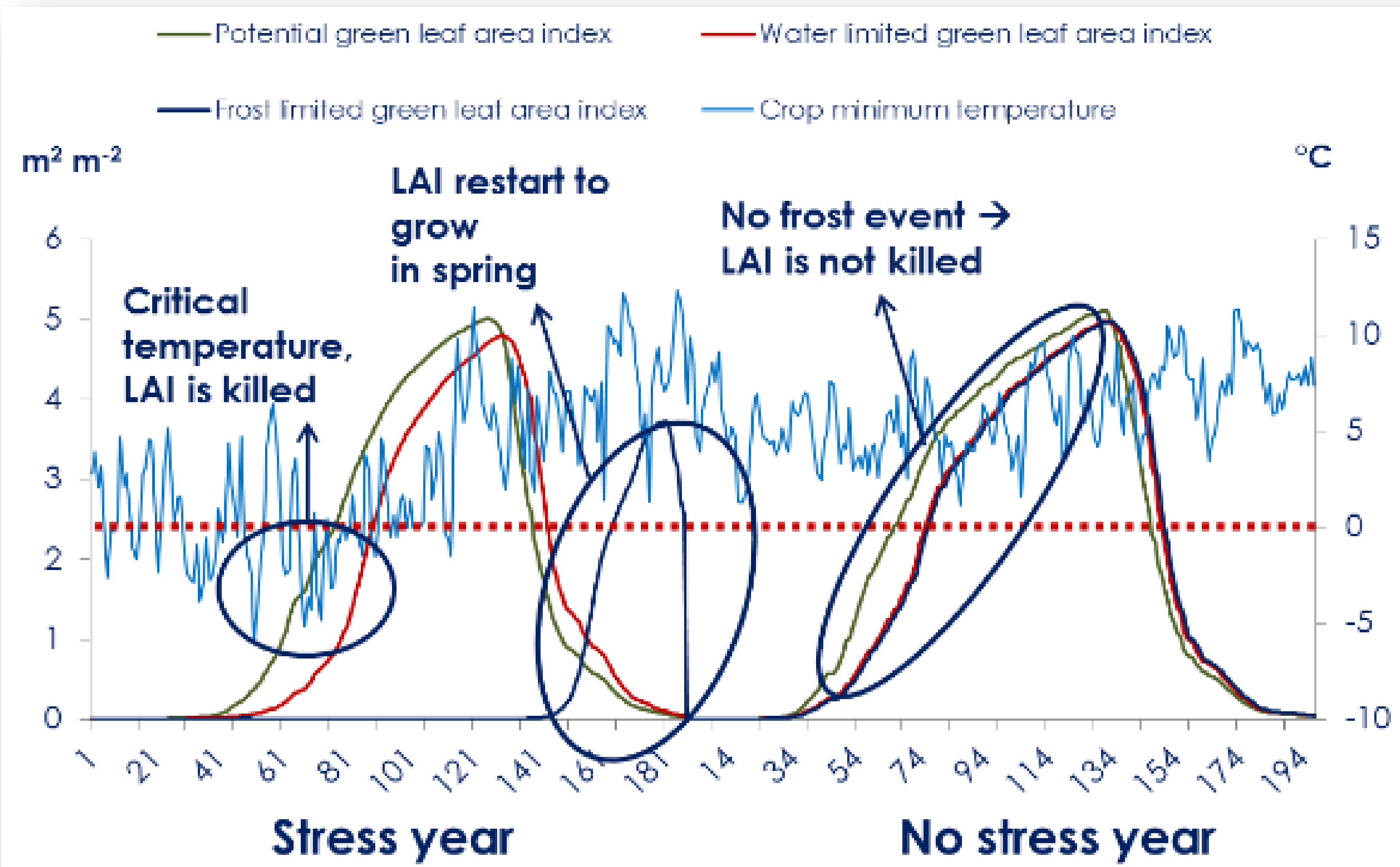
$$F_A = 1 / d_A \cdot \sum_1^{d_A} \min(F_T, F_W) \cdot \prod_1^{d_A} \min(F_F, F_H)$$

d_A: time window around anthesis
F_T: temperature factor (function of mean crop temperature)
F_W: water stress factor
F_F: frost factor (function of minimum crop temperature)
F_H: extreme heat factor (function of maximum crop temperature)

Stress functions / 1

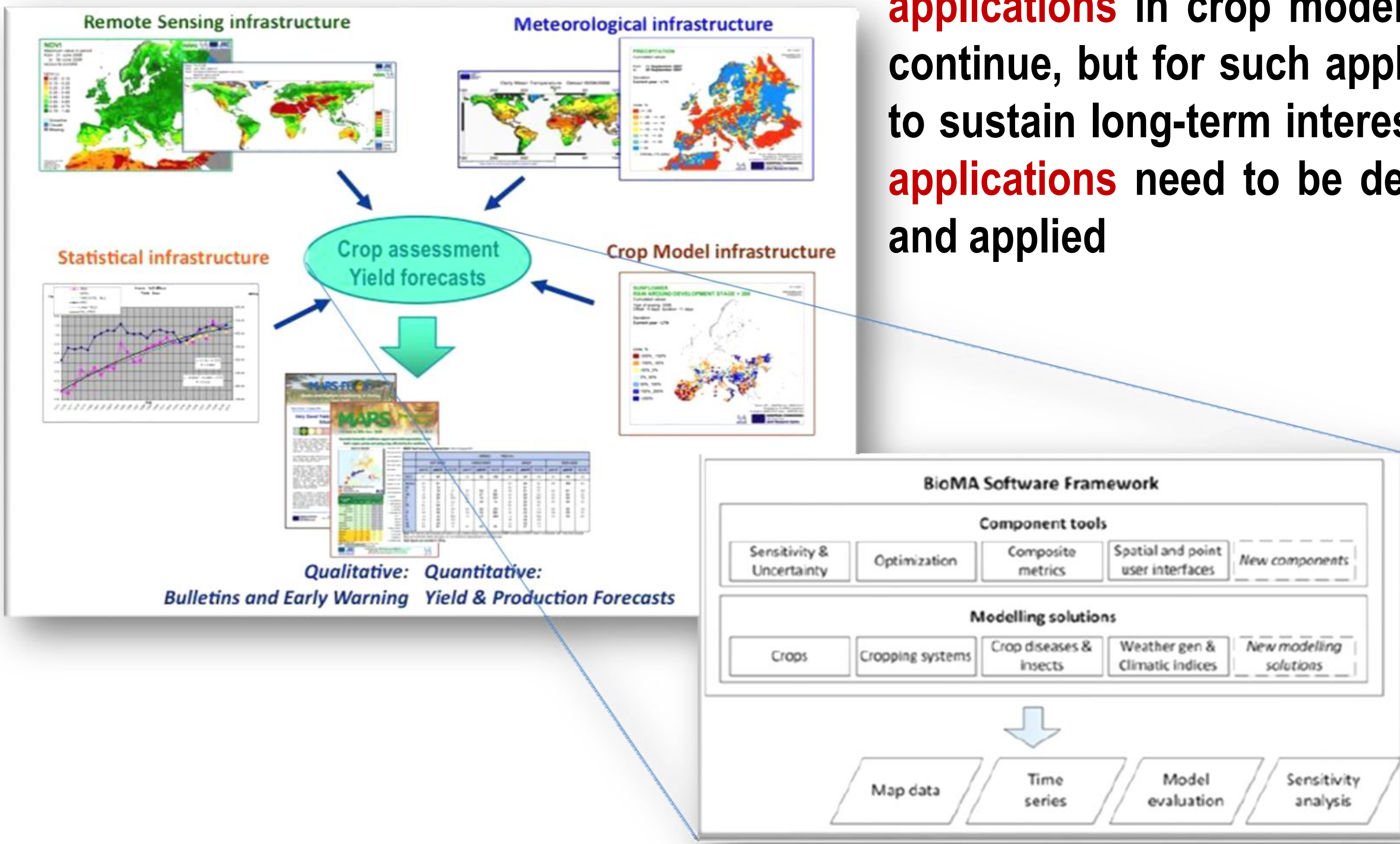


Stress functions / 2



Joint Research Centre agricultural yield forecasting with the platform BioMA

There is no doubt that **research applications** in crop modelling will continue, but for such applications to sustain long-term interest **policy applications** need to be developed and applied



Bellocchi et al. (2014)

Science-stakeholder dialogue

modextreme

agriculture facing extreme climatic events

Modelling the impact of extreme climatic events in agriculture

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