Australian National University

Robust Granger Causality Testing of the Effect of Natural and Anthropogenic Forcing on Global Temperature

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Motivation

- Causes of climate change remain controversial
- Natural application of Granger causality testing
- Revisit Kaufmann & Stern (1997) *Nature*

Granger Causality Testing

- Vector autoregression (VAR) model:

$$y_t = \beta_{1,0} + \sum_{i=1}^{p} \beta_{1,i} y_{t-i} + \sum_{j=1}^{p} \beta_{1,p+j} x_{t-j} + \varepsilon_{1t}$$

$$x_t = \beta_{2,0} + \sum_{i=1}^{p} \beta_{2,i} y_{t-i} + \sum_{j=1}^{p} \beta_{2,p+j} x_{t-j} + \varepsilon_{2t}$$

- Omitted variables a potential problem

Kaufmann & Stern (1997) *Nature*

- Used indirect method:
  - South → North, no controls
  - South ↛ North, GHG and SO_x controls

Kaufmann & Stern (1997) *Nature*

- Causal order reproduced in GHG&SUL GCM simulation but not in counterfactual
- Significance increased by recent data
- But criticized by Triacca (2001)

Recent Granger Causality Tests of Climate Change

Paper	**Variables**	**Method**	**GHG GC Temp?**	**Natural Forcing GC Temp?**
Triacca (2005)	Global temperature Log CO_2	Toda-Yamamoto	10%	n.a.
Kodra *et al*. (2011)	Global land temperature Log CO_2	Δ Granger	10% one period	n.a.
Bilancia & Vitale (2012)	Global temperature CO_2 **emissions**	Δ Granger	No	n.a.
Attanasio (2012)	Global temperature RF GHGs **or** various natural forcings	Toda-Yamamoto	Yes	No
Attanasio *et al*. (2012)	Global temperature RF GHGs **or** various natural forcings	Forecast error test	Yes	No
Pasini *et al*. (2012)	Global temperature RF GHG **or** Solar irradiance Controls: ENSO etc.	Forecast error test	Yes	No
Triacca *et al.* (2013)	Global temperature RF GHGs Controls: Natural forcings, ENSO etc.	Toda-Yamamoto	Yes	n.a.

Methods

- Toda-Yamamoto Granger Causality Test
- Select lag length – SBC – maximum 4 lags
- Add 2 extra lags but do not include in restriction
- Wald test statistic – chi-square

Data Sources

Temperature: HADCRUT4, GISS3 global surface temperature

Ocean heat content: Levitus 0-700m

Greenhouse gases: GISS radiative forcing data

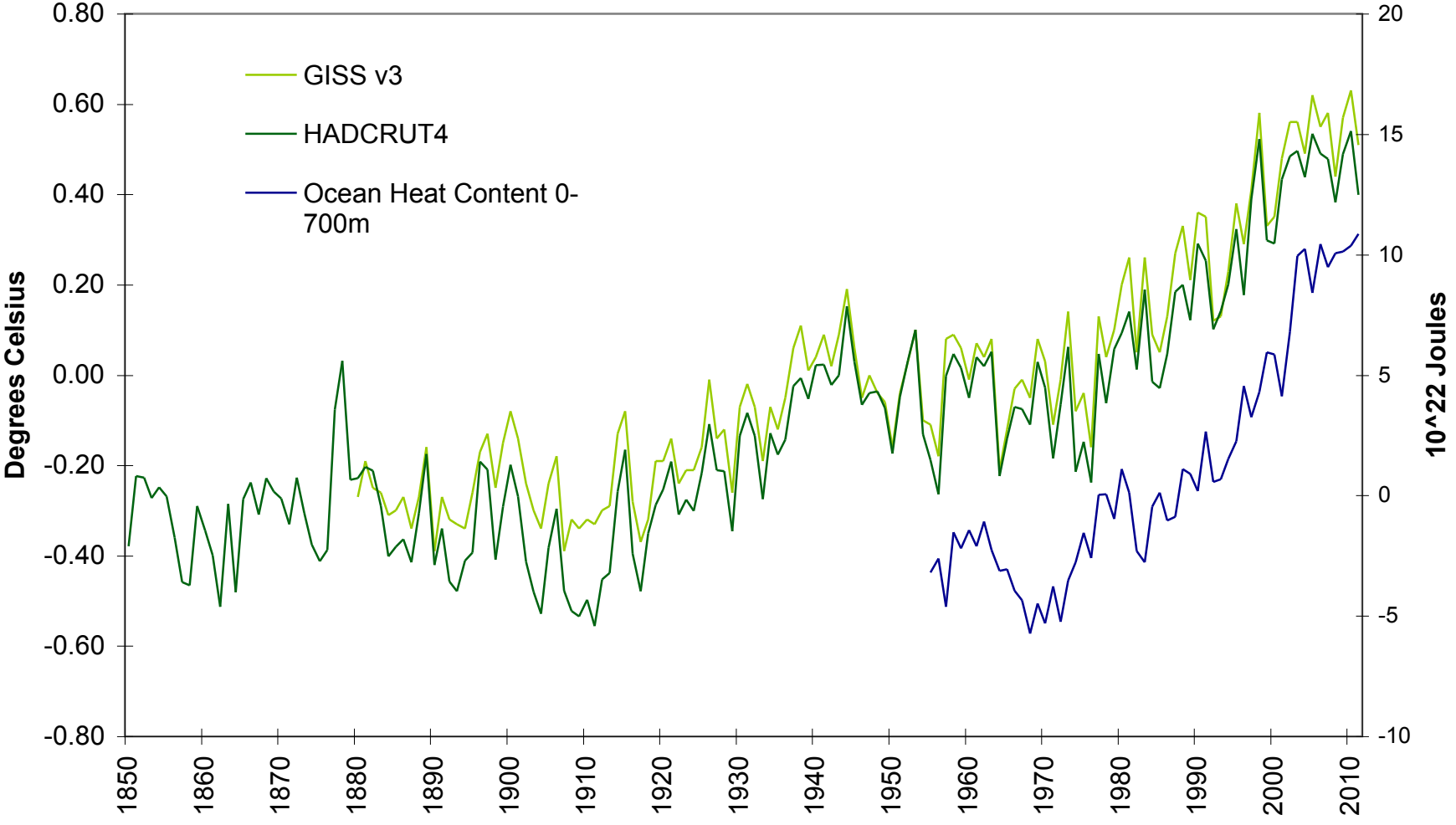
Volcanic sulfate aerosol: GISS optical thickness data

Anthropogenic sulfur emissions: Smith *et al*. (2011) and Klimont *et al*. (2013)

Solar irradiance: GISS/Lean

Black and organic carbon: RCP 8.5 historic series

Global Temperature and Ocean Heat Content



Alternative Samples, Data, Models, and Scenarios

Samples: 1850-2011 and 1958-2011

Temperature: HADCRUT4 or GISS3

Ocean heat content: With or without

Aggregation:

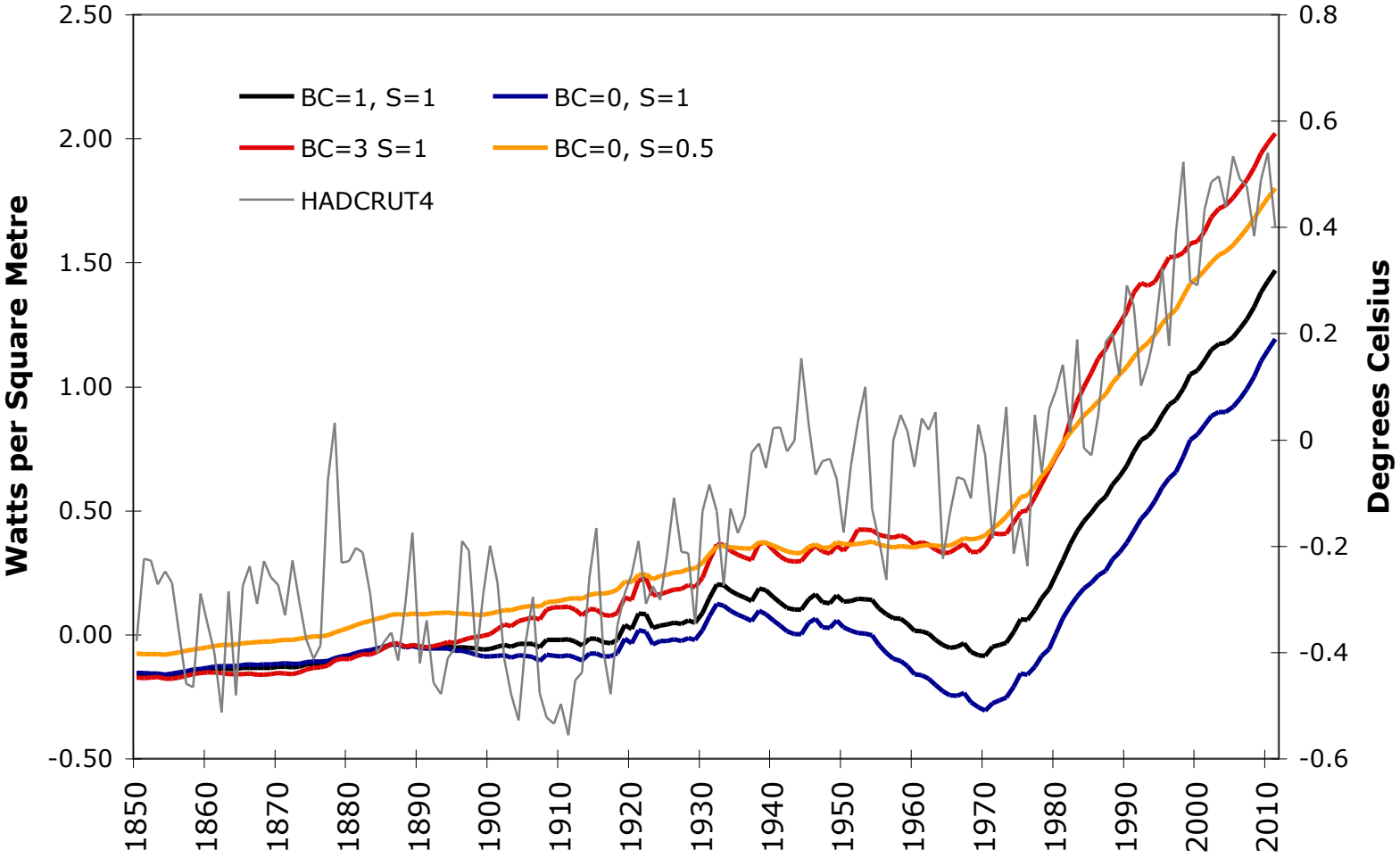
I	Total radiative forcing	
II	Anthropogenic RF	Natural RF
III	GHGs, sulfate aerosol, black carbon	Solar irradiance, volcanic aerosol

Alternative Samples, Data, Models, and Scenarios

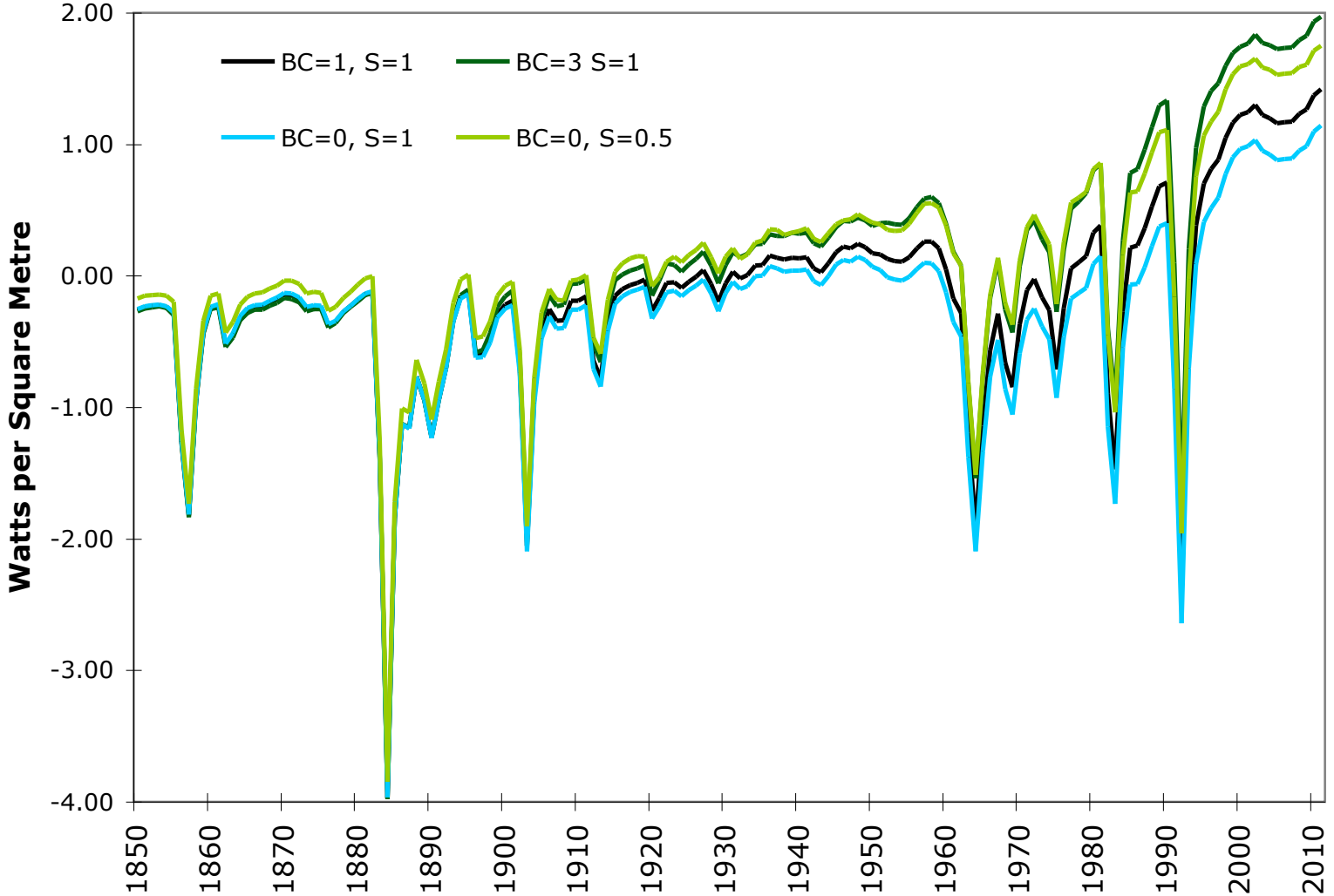
Scenarios for models I and II:

BC = 1, S = 1	Default sulfate aerosol, RCP 8.5 black carbon
BC = 0, S = 1	Default sulfate aerosol, black carbon RF = 0
BC = 3, S =1	Default sulfate aerosol, black carbon RF = 3*RCP 8.5
BC = 0, S = 0.5	Half default sulfate aerosol RF, black carbon RF = 0

Global Temperature & Anthropogenic Forcing



Total Radiative Forcing



Granger Causality Tests: 1850-2011

Alternative Scenarios	BC = 1 S = 1	BC = 0 S = 1	BC = 3 S =1	BC = 0 S = 0.5
Model I. TEMP RFTOT				
RFTOT causes TEMP	**0.0021**	**0.0048**	**0.0004**	**0.0008**
TEMP causes RFTOT	0.3475	0.4428	0.2591	0.2836
Model II. TEMP RFANTH RFNAT				
RFANTH causes TEMP	0.1925	0.1467	0.6490	**0.0297**
RFNAT causes TEMP	**0.0292**	**0.0295**	**0.0104**	**0.0238**
TEMP causes RFANTH	0.1211	0.1137	**0.0762**	**0.0931**

Figures are p-values for rejecting the null hypothesis of no causation.
Values in **red** reject the null hypothesis of no causality at 5% level, **orange** at 10% level

Granger Causality Tests: 1958-2011

Alternative Scenarios	BC = 1 S = 1	BC = 0 S = 1	BC = 3 S = 1	BC = 0 S = 0.5
Model I. HADCRUT4 RFTOT				
RFTOT causes TEMP	**0.0003**	**0.0005**	**0.0001**	**0.0058**
TEMP causes RFTOT	0.8388	0.8583	0.8166	0.5334
Model II. HADCRUT4 RFANTH RFNAT				
RFANTH causes TEMP	0.1836	0.3196	0.2294	**0.0013**
RFNAT causes TEMP	**0.0007**	**0.0033**	**0.0002**	**0.0008**
TEMP causes RFANTH	0.7735	0.6204	0.5015	0.3514

Figures are p-values for rejecting the null hypothesis of no causation.
Values in **red** reject the null hypothesis of no causality at 5% level, **orange** at 10% level

Granger Causality Tests: 1958-2011 + Ocean Heat Content

Alternative Scenarios	BC = 1 S = 1	BC = 0 S = 1	BC = 3 S = 1	BC = 0 S = 0.5
Model I. HADCRUT4 RFTOT OHC				
RFTOT causes TEMP	**0.0031**	**0.0055**	**0.0010**	**0.0045**
TEMP causes RFTOT	0.5532	0.5968	0.5091	0.6199
Model II. HADCRUT4 RFANTH RFNAT OHC				
RFANTH causes TEMP	**0.0829**	0.2649	**0.0683**	**0.0006**
RFNAT causes TEMP	**0.0165**	**0.0217**	**0.0111**	**0.0203**
TEMP causes RFANTH	0.3438	0.1824	0.6671	0.9184

Figures are p-values for rejecting the null hypothesis of no causation.
Values in **red** reject the null hypothesis of no causality at 5% level, **orange** at 10% level

Granger Causality Tests: Disaggregated Forcings

Sample	1850-2011	1958-2011	
Ocean Heat Content	No	No	Yes
RFGHG causes TEMP	**0.0003**	**0.0026**	**0.0221**
RFSOX causes TEMP	0.3187	**0.0460**	**0.0040**
RFBC causes TEMP	0.6884	0.6700	0.4065
RFGHG, RFSOX, & RFBC cause TEMP	**0.0082**	**0.0090**	**0.0089**
RFVOL causes TEMP	**0.0134**	**0.0470**	**0.0071**
RFSOL cause TEMP	0.2380	0.1138	0.1043
RFVOL & RFSOL cause TEMP	**0.0121**	**0.0678**	**0.0131**
TEMP causes RFGHG	**0.0255**	**0.0003**	**0.0016**

Figures are p-values for rejecting the null hypothesis of no causation.
Values in **red** reject the null hypothesis of no causality at 5% level, **orange** at 10% level

Conclusions

- Both natural and anthropogenic causes of climate change
- Feedback from temperature to GHGs
- No apparent effect from black carbon
- Sulfate aerosol effect may be weaker
- Model specification very important

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