Health effects of temperature and its interaction with air pollution

Methodological issues and preliminary results from a multicountry study

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Outline

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Temperature and health

Interest in temperature-related health effects has grown after recent **extreme weather events** and evidence of **climate change**

Several epidemiological studies have investigated the relationship between **temperature and mortality**, in particular heat (Basu Epi Review 2002, Basu Env Health 2009)

However, temperature-health associations are still **poorly characterized**, especially regarding susceptibility and modifying factors

In particular, several studies have assessed the **synergistic effects** of temperature and air pollution, reporting not entirely consistent results

Projecting the impact

Growing literature including studies on health impact projections under climate change scenarios (Huang EHP 2011)

Several proposed approaches (Kinney Env Sci & Pol 2008), with two common steps:

1. specify a **risk function** defining the exposure-response relationship
2. apply the function to **temperature distribution** projected in the future under alternative scenarios

However, temperature-related impact projections are based on several **assumptions**, and face important **methodological/practical issues**

Assumptions and methodological issues

- **Definition** of temperature effects: absolute or relative scale?
- **Complexities in modelling** the exposure-response relationships: non-linearity, lagged effects, pooling multi-parameter estimates
- **Geographical heterogeneity**: little information on susceptibility factors responsible for modifying the risk
- **Temporal variation**: superficial models for **adaptation/acclimatization**, with no info on its timescale or drivers

The MCC collaboration

The **multi-city multy-country (MCC) collaborative study** has attempted to address some limitations in the characterization of temperature-health associations

Advantages:

- **Global perspective**: data from 410 locations within 18 countries, investigating populations with different characteristics and exposed to a various range of climates
- **Flexible modelling framework** allowing non-linear/lagged responses, separation of effects due to cold/heat and moderate/extreme temperature, and assessment of effect modification

MCC participants and funding

Participants (alphabetical order):

- Ben Armstrong
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- Michelle Bell
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- Masahiro Hashizume
- Yasushi Honda
- Haidong Kan
- Ho Kim
- Eric Lavigne
- Paola Michelozzi
- Samuel Osorio
- Paulo Hilario Saldiva
- Joel Schwartz
- Matteo Scortichini
- Xerxes Seposo
- Francesco Sera
- Aurelio Tobias
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- Dang Tran Ngoc
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- Antonella Zanobetti
- Ariana Zeka

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The MCC dataset

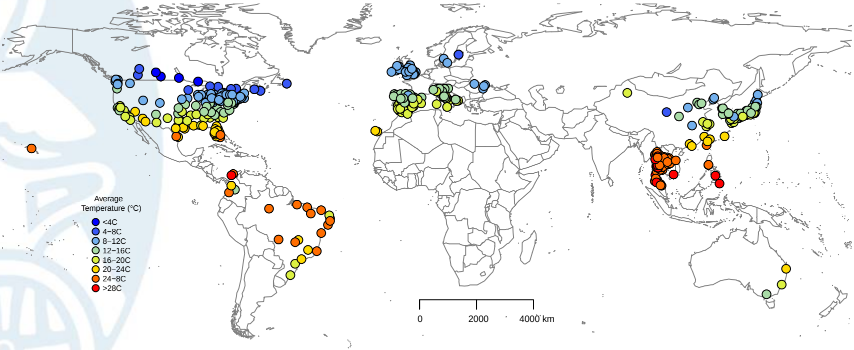
Largest dataset ever collected: data from **410 locations** in **18 countries** within the period 1972–2012, including **85 million** deaths

Countries: Australia, Brazil, Canada, China, Colombia, Ireland, Italy, Japan, Moldova, Philippines, South Korea, Spain, Sweden, Taiwan, Thailand, UK, USA, Vietnam

Daily time series of mortality counts (all-cause, CVD, respiratory, others), temperature (mean, min, max), humidity, air pollution (PM_x, O_3, NO_x, SO_2, CO)

Location-specific **meta-variables** on climatological, geographical, infrastructural, demographic, socio-economic characteristics

Map of MCC locations



Data for impact projection

WATCH Forcing dataset

- Global re-analysis dataset of daily meteorological variables for the period 1979–2009, with resolution of 3 hours over a $0.5^\circ \times 0.5^\circ$ grid

ISI-MIP dataset

- Global simulation dataset of daily meteorological variables including historical (1860–2005) and projection (2006–2100) periods
- Simulations from 5 global climate models (GCM) (HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, and NorESM1-M) from the CMIP5 archive of IPCC, under emission scenarios RCP4.5 and RCP8.5
- Downscaled over a $0.5^\circ \times 0.5^\circ$ grid through bias correction using WATCH data

Statistical models

Two-stage time series analysis extending a framework developed in air pollution studies, *e.g.* NMMAPS (Samet HEI 2000)

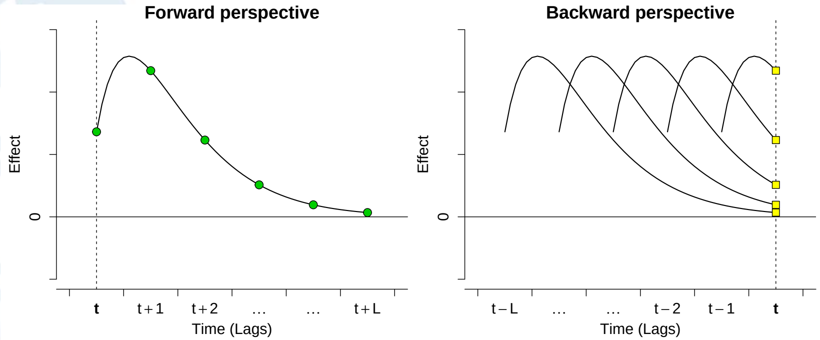
1. First-stage generalized linear model with quasi-Poisson family, modelling the mortality count μ_t in day t as:

$$\log\left[\mathrm{E}(\mu_t)\right] = \alpha + \sum_{\ell=\ell_0}^{L} f \cdot w(x_{t-\ell}, \ell; \boldsymbol{\theta}) + \sum_{j} g_j(z_{jt}; \boldsymbol{\xi}_j) + s(t; \boldsymbol{\delta}) + \mathrm{I}(\mathrm{d_t}; \boldsymbol{\gamma})$$

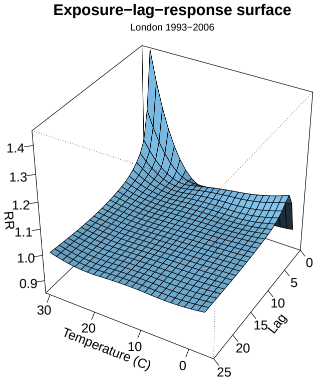
   - a **distributed lag non-linear model** (DLNM), expressing a bi-dimensional *exposure-lag-response* function $f \cdot w(x, \ell)$ of temperature x over lag ℓ
   - functions modelling time-varying confounders z_{jt} (*e.g.* air pollution)
   - temporal trends modelled with functions of time t and day of the week d

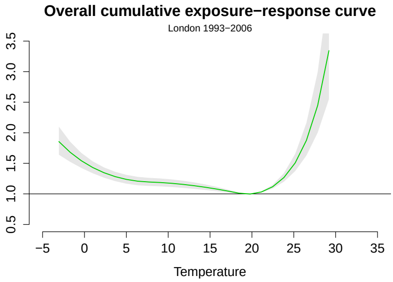
2. Second-stage **multivariate meta-regression** to pool results across locations

DLNM: conceptual framework

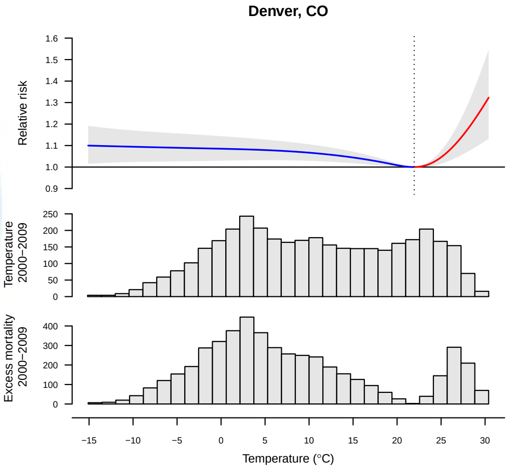


Exposure-lag-responses





Centering, counterfactual, separation



First analysis

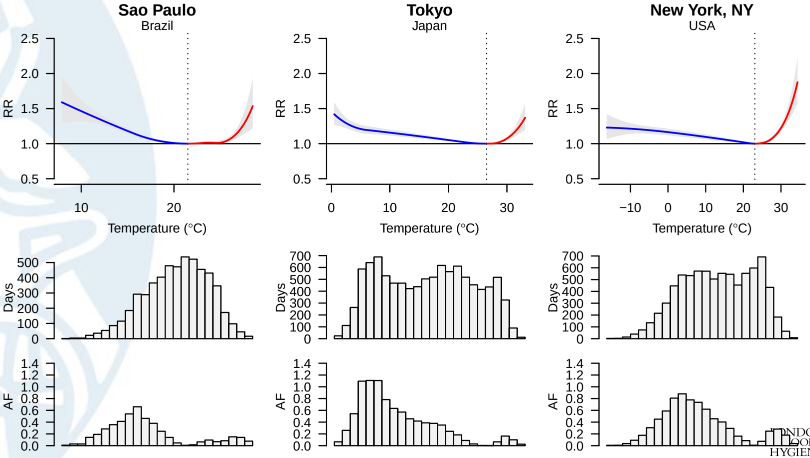
Two-stage time series analysis of **384 locations in 13 countries** of the MCC dataset in the period 1985–2012

Estimation of the location-specific **overall cumulative exposure-response** between temperature and all-cause mortality

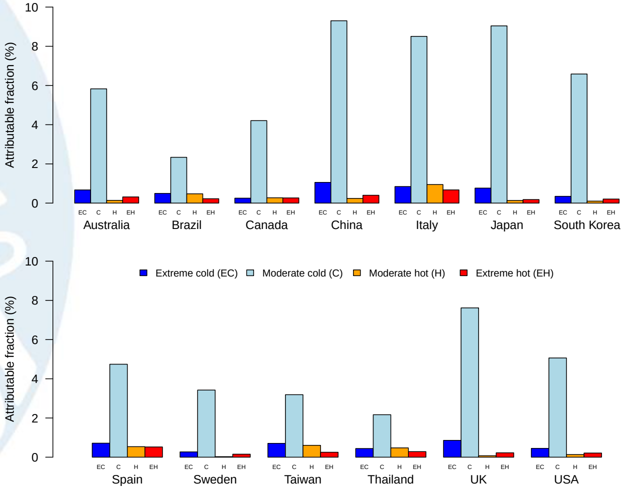
Computation of the **attributable fraction** of deaths by location/country, in total and separated by moderate/extreme cold/heat

Results previously published (Gasparrini Lancet 2015)

Location-specific estimates



Country-specific estimates



Second analysis

Extension of the two-stage time series analysis to **395 locations in 15 countries** of the MCC dataset

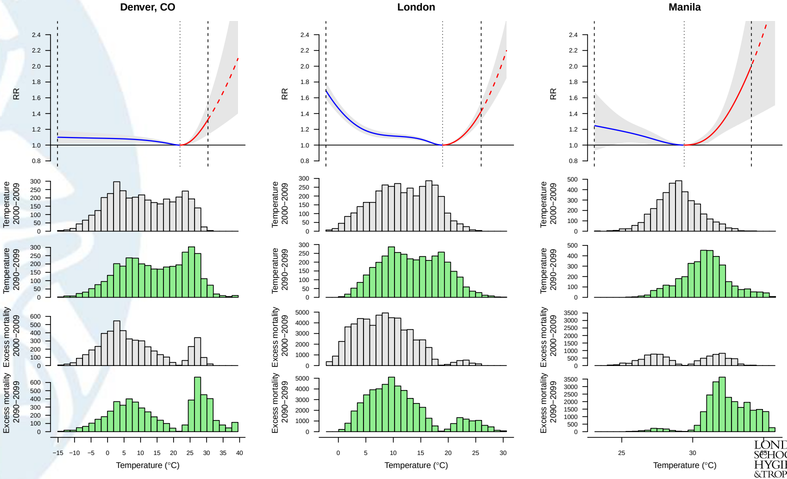
Derivation of (stable) location-specific **future mortality series**

Derivation of location-specific, bias-corrected **future temperature series** for:

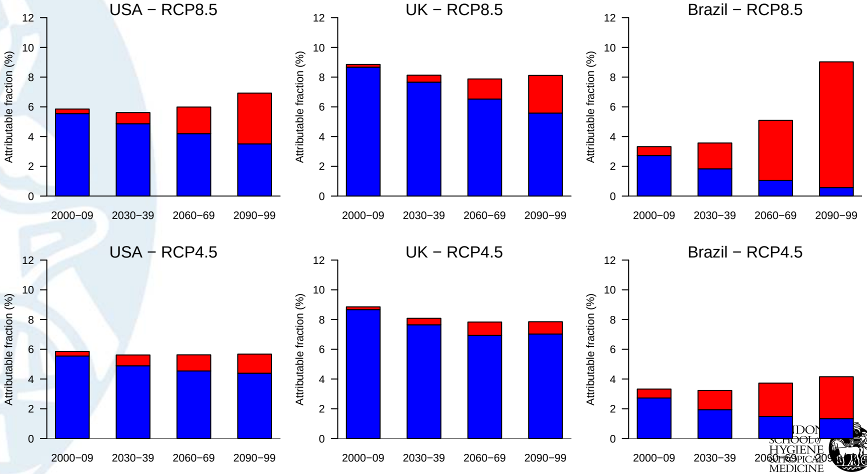
- historical period (1980–2009)
- projection period (2010–2099) for each GCM and two emission scenarios (RCP4.5 and RCP8.5)

Estimation of temperature-related impact **in the future**, averaged across GCM (ensemble) and aggregated by decade for each RCP

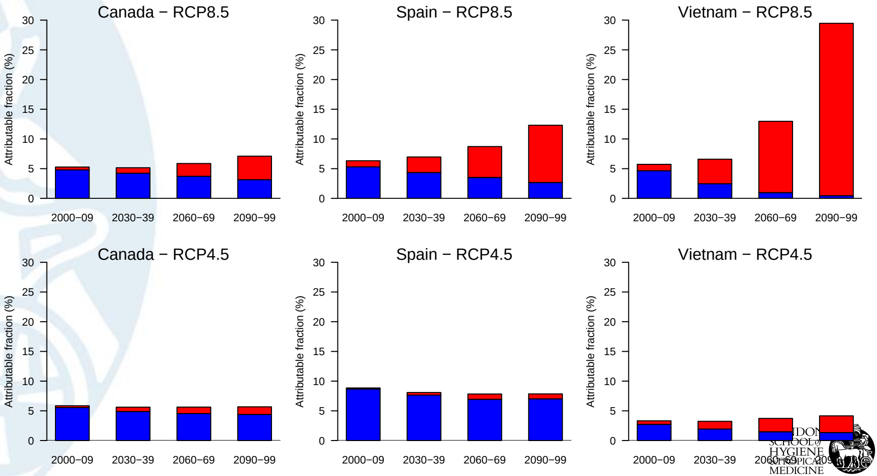
Projecting the impact: by location



Projecting the impact: by country – I

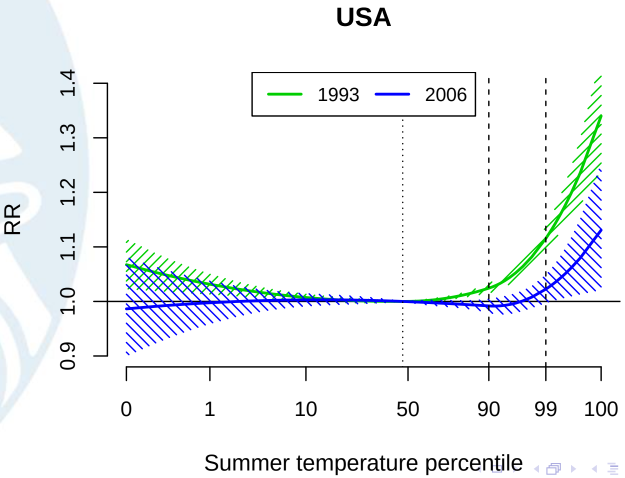


Projecting the impact: by country – II



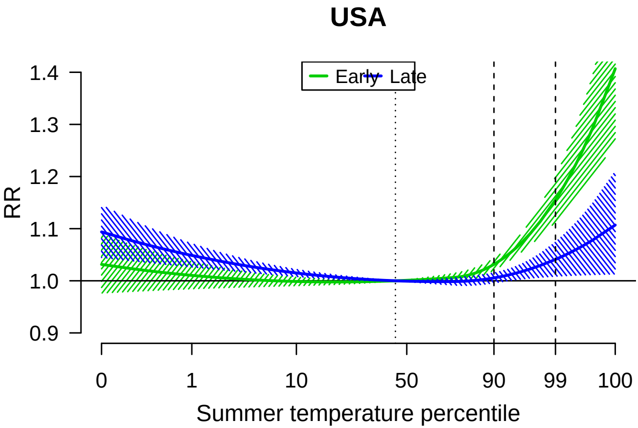
Adaptation and acclimatization – I

Gasparrini EHP 2015



Adaptation and acclimatization – II

Gasparrini AJE 2016 (to appear)



Synergistic effects of temperature and pollution

Huge literature on the topic: **tens of studies** (hundreds?) assessing effect modification

Most of the studies reporting **increased effects of air pollution** during days of high temperature

Results **not entirely consistent**: differences between and within studies for specific pollutants and cold vs heat

Differences in:

- **designs** (e.g. all-year vs season-specific)
- **temperature definitions** (summer/winter, heat wave, continuous)
- **modelling approaches**

Modelling temperature-pollution interactions

Simplifying $f \cdot w(x, \ell)$ and $g(z)$ in model equation above, usually with:

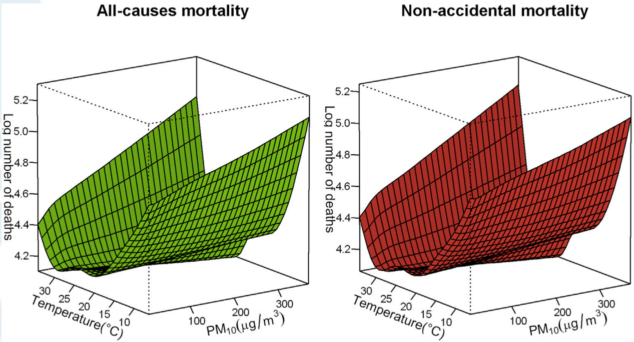
- non-linear or linear-threshold $f(x)$ for temperature x
- linear untransformed z for pollution z
- no or very limited account for the **lag structure**

Developing interaction terms:

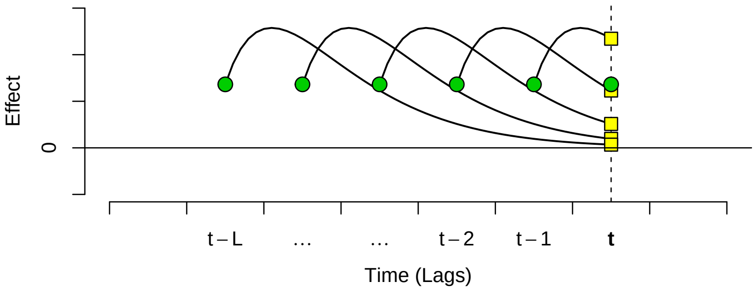
- Interaction between **single terms** (Stafoggia AJE 2008, Carder OEM 2008)
- **categorization** of the interactive term (Cheng JEpid 2012, Breitner ScTotEnv 2014, Jhun EnvInt 2014, Kim ScTotEnv 2015)
- **bivariate** surface interaction models (Robert EnvRes 2004, Ren EnvInt 2008, Li ScTotEnv 2011, Burkart EnvPoll 2013, Li EnvPoll 2015)

Bivariate surface interaction models

Li EnvPoll 2015



Forward and backward interaction



In conclusion

- Temperature is an important environmental risk factor associated to substantial health risks
- The associated risk is expected to change dramatically in the future due to climate change, with differential patterns for heat/cold and across locations/countries
- Several aspects of temperature-health associations are still partly characterized, in particular regarding geographical heterogeneity and mechanisms of adaptation/acclimatization
- Modelling interactions with air pollution presents important methodological problems, regarding both the specification of statistical methods, the definition of the conceptual model and the interpretation of the results