# Climate Hazards: Outline

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**Questions for co-authors...**

1. Only max temperature matters to heat extremes – unlike hardiness where plants gain/lose tolerance, this doesn't really happen for heat extremes, right?
2. What extremes to think about? Heat, cold, drought ... ?
3. Is there any literature on heat damage as limiting seasons?
4. Any ideas on figures?

## 1 Outline

1. Introduction: mean versus variance in climate change biology
    (a) Increasing interest in impacts of extremes
    (b) Lots on thermal curves and variance, including lots on Jensen's inequality
    (c) Lots of interest in shifts in variance from theoretical perspective, but often not linked to empirical reality
    (d) Most find increasing variance will reduce fitness (e.g., Vasseur), but how accurate is this?
    (e) As variance is a fundamental part of life history theory and physiology, it is likely more complicated
    (f) Here we ...
2. Why extremes matter
    (a) Overview of basics
        i. Lots on mean versus variance theoretically in life history theory (colors of noise etc.)
        ii. And in physiology: mean development, but also how extremes limit distributions
        iii. Molecular studies back up this complexity: variability versus mean temperatures underlie pathways to some events
        iv. But climate change smears across these two separate approaches as we need to predict outcomes across the full life stages of individuals within a population and across species.

(b) Fundamental trade-off in life history that climate change is (most?) rapidly altering: growing season length (mean) versus risk (variability often)
    i. Frost risk
    ii. Drought risk
(c) What extremes? (could move to box 2?)
    i. Heat: just the max (right?)
    ii. Cold
        A. Max (hardiness at max period)
        B. Transition periods
    iii. Drought
    iv. Others?
(d) Why biological hazards should be easier to predict than climatic hazards (transition to next section with this? Or find it new home?)
    i. Extremes in climate science are defined statistically usually – they are rare by definition which makes them tricky
    ii. But we're not talking about that, we're talking about climate hazards, which depend on biological limits, often thermal limits

3. When extremes matter (need Fig)
    (a) Variance shifts in certain biological periods matter a lot more than others: Likely windows for hazards ...
        i. Transitional climatic periods (spring/fall) and hottest summer months
        ii. But also depend a lot on phenology
4. PHENOFIT case study
    (a) Do means versus variability shifts alone lead to increases or decreases in fitness? Or is is messier?
    (b) Additive effects...
5. From models to forecasting (*this section needs work*)
    (a) Need more fitness data
    (b) Need more data on events and their impacts (crops?)
    (c) Need better molecular studies of mean versus variability
    (d) Need to bridge the observational/experimental gap for heat extremes (especially)

**Boxes?**

1. Box 1: Why we're bad at predicting extremes
    (a) We may often have poor intuition about what is shifting ... How much are means versus variability shifting?
        i. Info from the literature
            A. Basics from IPCC?

B. Refs from Ben?
C. Extremes versus variability

ii. Lots of variance patterns in temperature are narrowing:
A. Daily temperature ranges
B. Elevation, latitude

(b) Case study in Europe
i. Variability across space (sites)
ii. Shifts since 1950 by month
iii. Change over time versus sites: Variability across space decreasing?
iv. Projections

2. Box 2: High versus low temperatures

## 2 Manuscript text

**Title:** Seasonal pressure points of climate change

**Abstract**

Climate change is reshaping growing seasons globally with major impacts on natural and agricultural ecosystems. Yet we are uncertain exactly how, where, and when impacts will be most pronounced. We show how fundamental life history theory and physiology can help identify the pressure points of climate change—seasonal periods when shifts in climate interact with development to lower growth, reproduction or survival. Using an integrated model of the full annual cycle of plant growth, reproduction and survival (PHENOFIT), we will compare the impacts of future warming versus shifts in frost events on the fitness of three tree species (*Fagus sylvatica, Pinus sylvestris, Quercus robur*). This framework will help identify the challenges and opportunities in adapting to climate change across European forests.