# The importance of considering extreme and rare events in environmental management

Ullrika Sahlin, Centre of Environmental and Climate Research

Lund University, Sweden

Ullrika.Sahlin@cec.lu.se

http://www.cec.lu.se/ullrika-sahlin

Train departs

Now

Time

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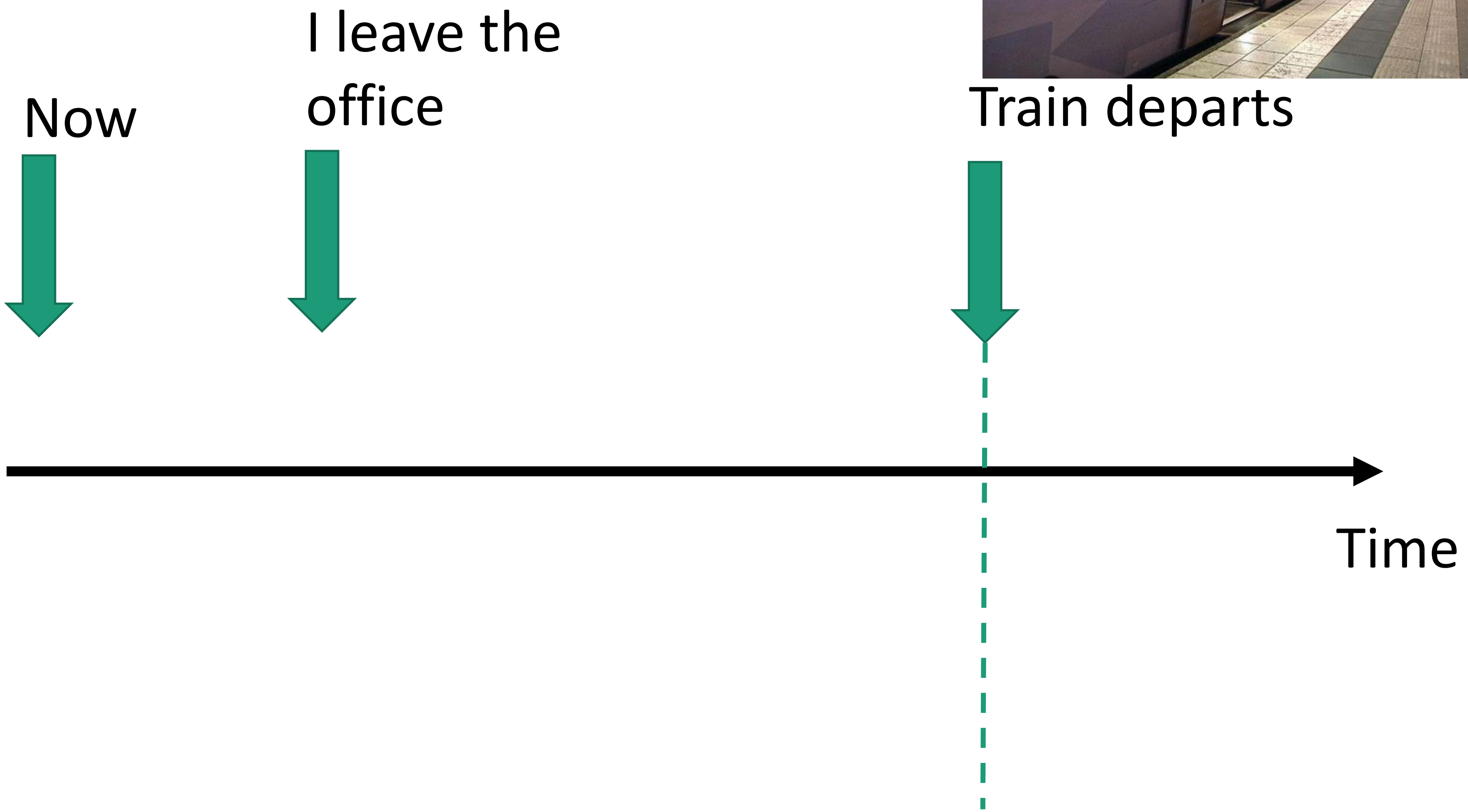


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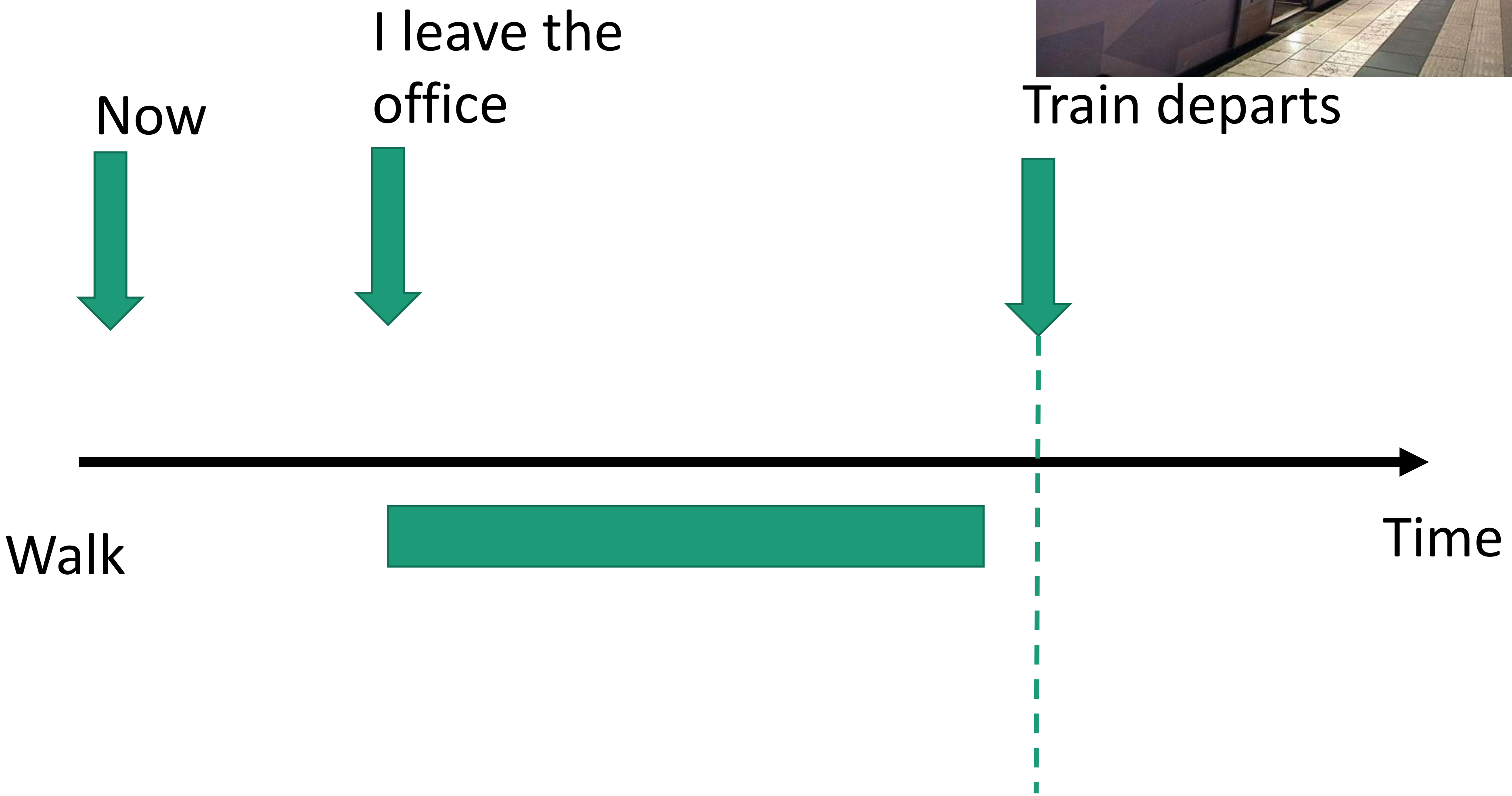


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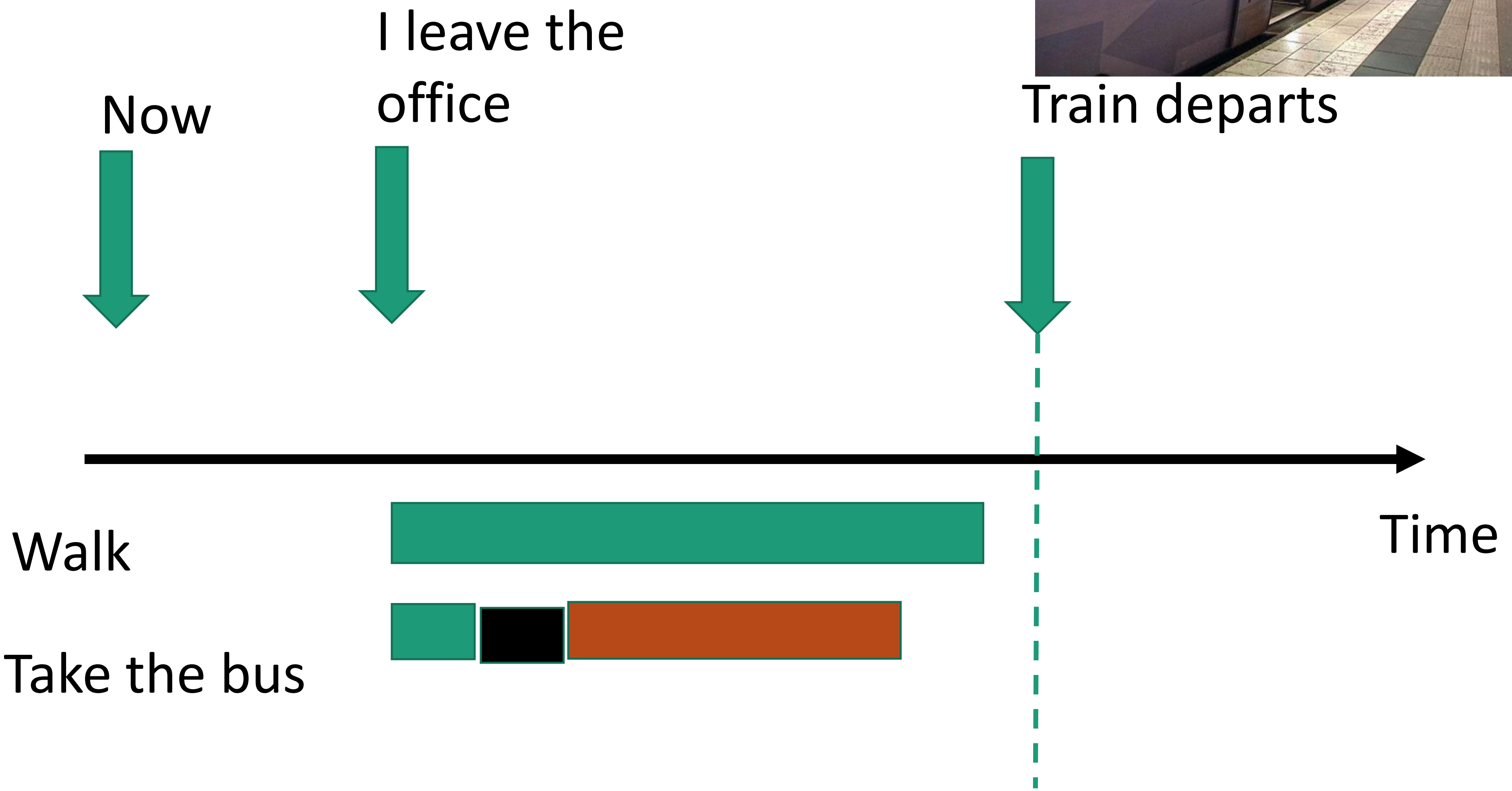


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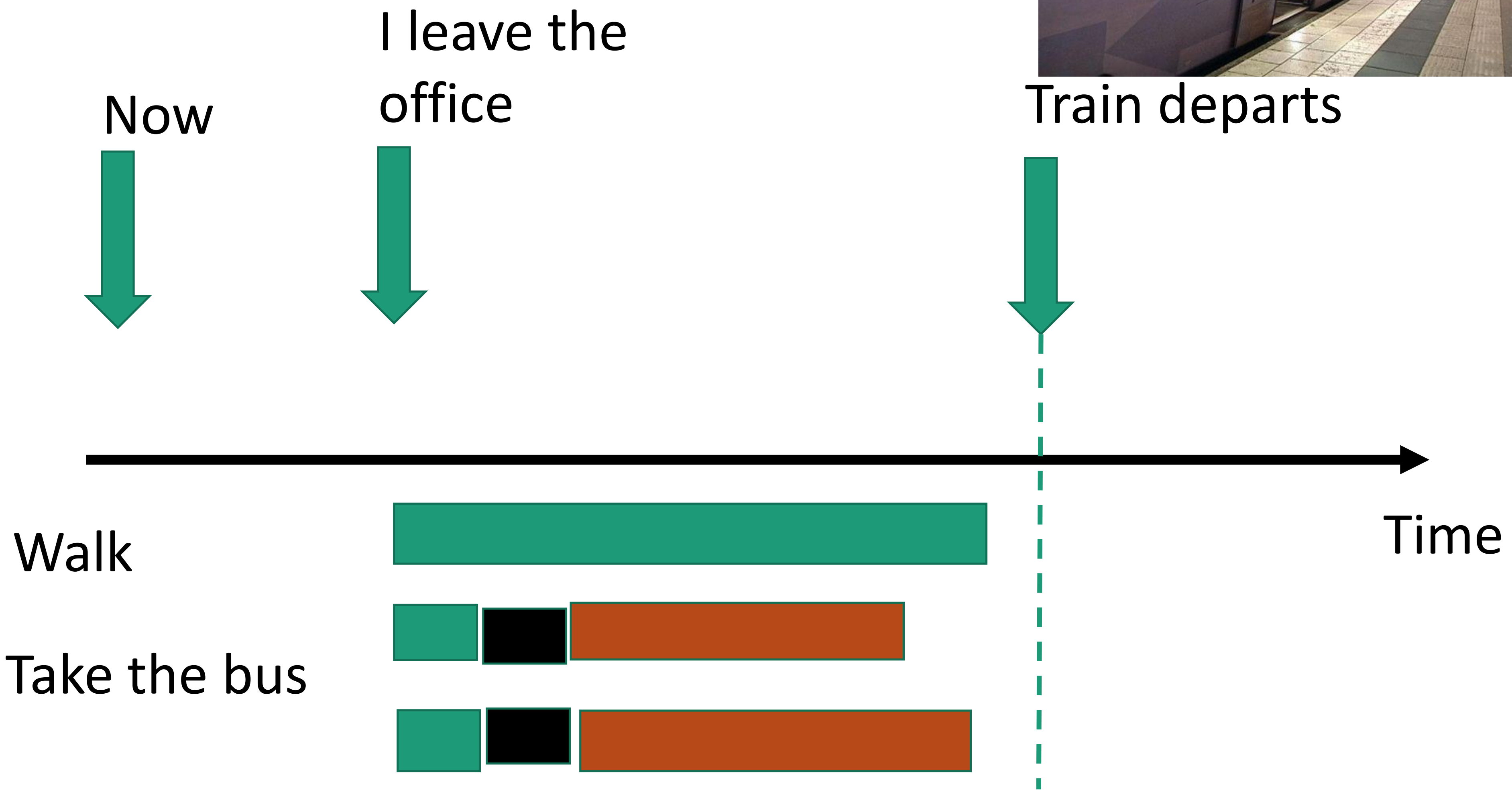

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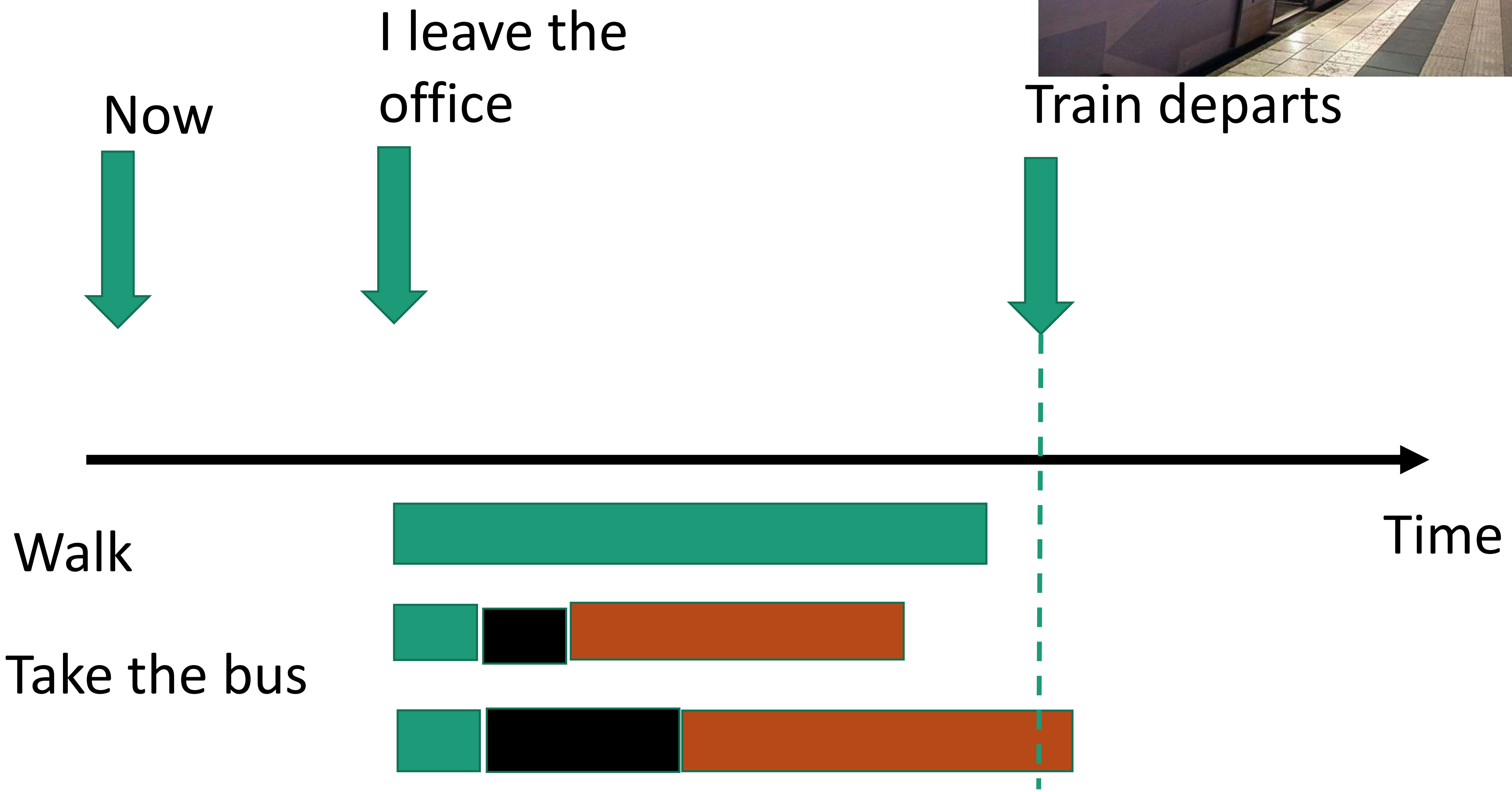


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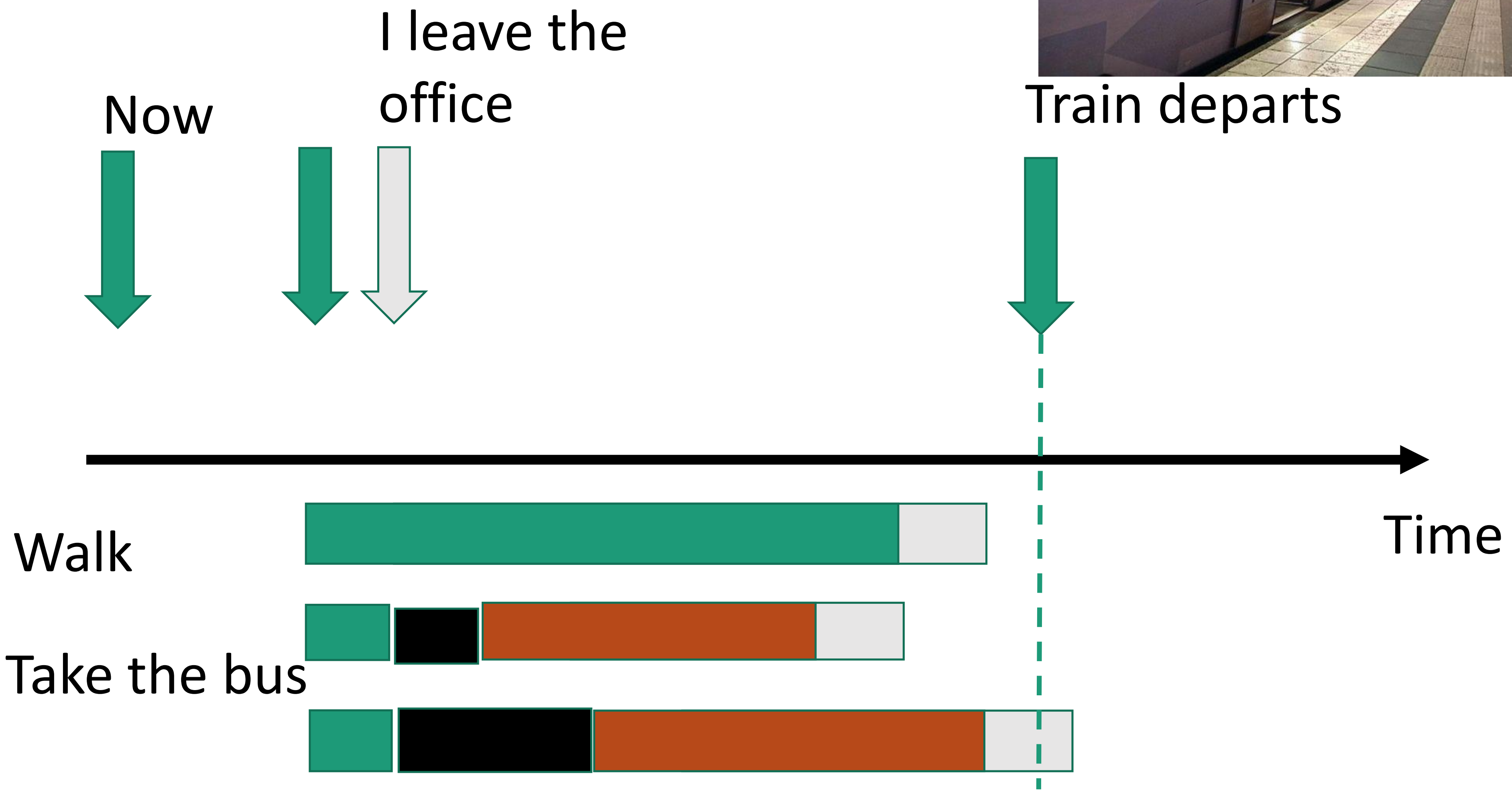
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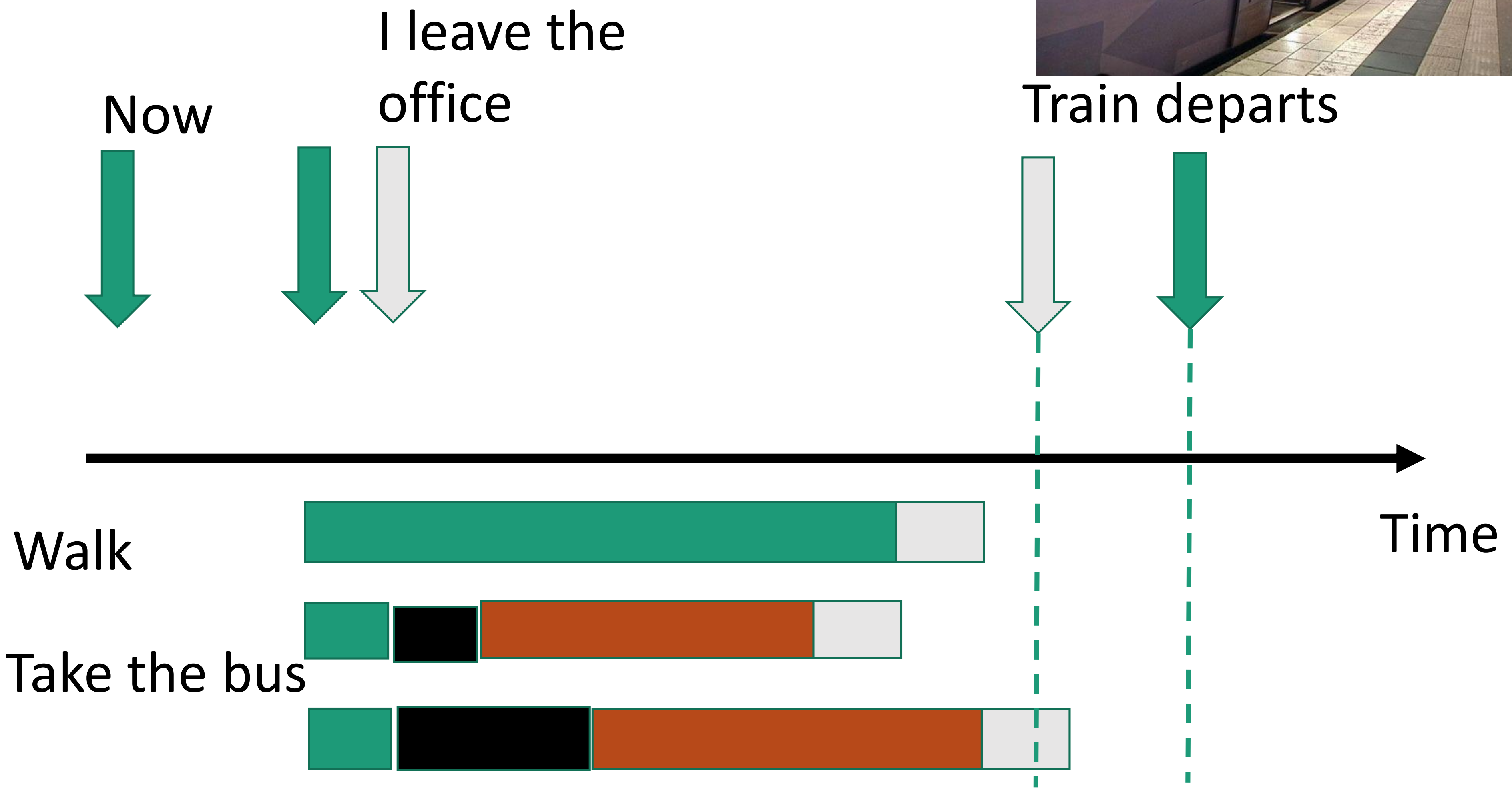
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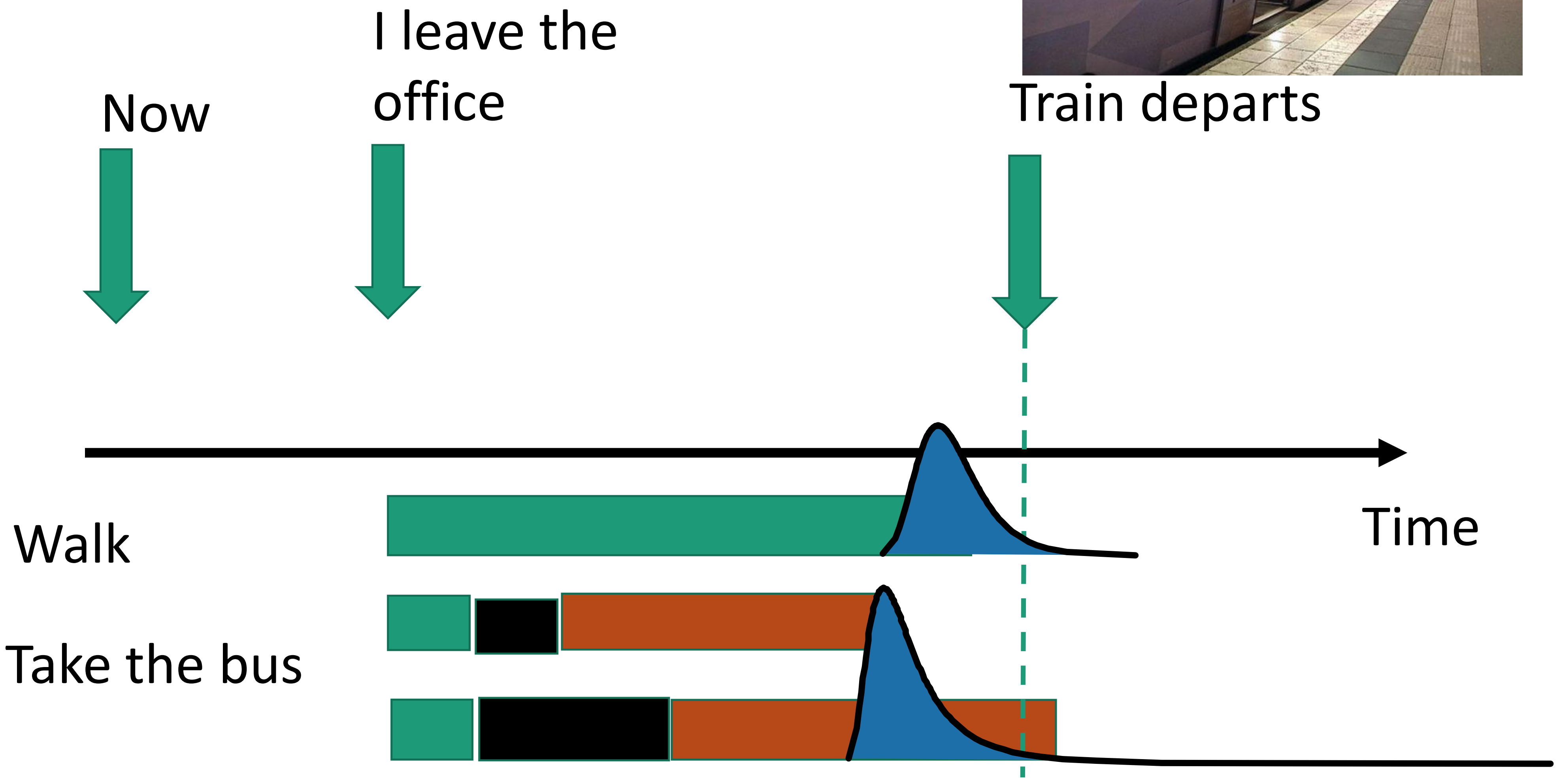
# What makes a decision?

- An agent
- Her values
- An idea of what is a good decision
- Decision alternatives
- Uncertainties in the outcomes of these alternatives

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# Outline

- Environmental management
- Learning & forecasting to make decisions
- Extreme events and uncertainty
- Consider extreme events in system and knowledge dimensions
- More than one scientific perspective on extreme events

# Coastline erosion and sea level rise

- Large economic loss
- Threatens biodiversity and recreation
- Loss of protection against high sea levels
- Requires coordinated management


Caroline Fredriksson and Hans Hansson, LTH.
Aktuella Frågor 27 April 2017

SYDSVENSKAN

# Environmental management

- Several decision makers
- Many people affected in different ways
- High values at stake
- Long term effects
- Irreversible effects
- Solutions requiring a sacrifice of another value
- Complex systems
- Large variability (i.e. inherent randomness in the system)
- Scientific uncertainty
- Need to communicate the limits of what we know
- Management urgent

# Environmental management

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Research type A
Understanding and managing environmental problems

Research type B
How to conceptualise, assess and find management solutions to environmental problems

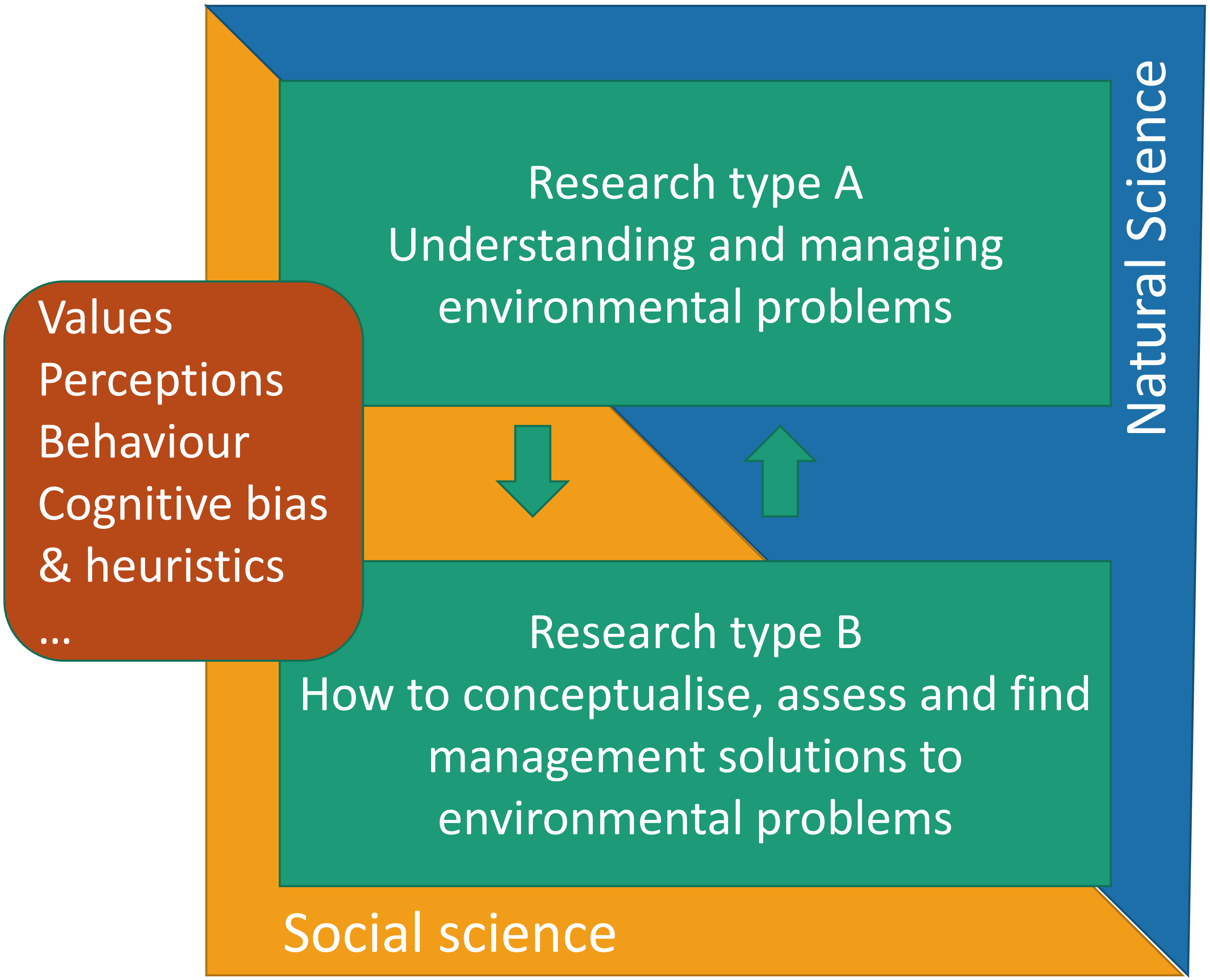
Learning
&
Forecasting

Uncertainty
&
Decision making

Modified from Aven, Keynote lecture, Nordic Chapter Risk Conference, Lund, 2015.

Clark et al 2001. Ecological forecasts: An emerging imperative. Science.

Spiegelhalter and Riesch. 2011. Don't know, can't know: embracing deeper uncertainties when analysing risks. Philosophical Transactions of the Royal Society.

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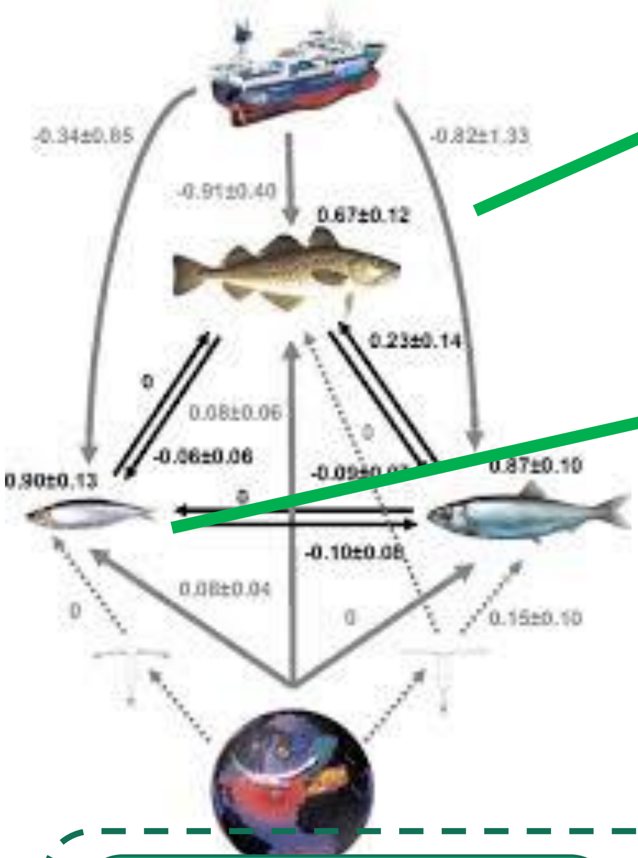
Clark et al 2001. Ecological forecasts: An emerging imperative. Science.
Spiegelhalter and Riesch. 2011. Don't know, can't know: embracing deeper uncertainties when analysing risks. Philosophical Transactions of the Royal Society.

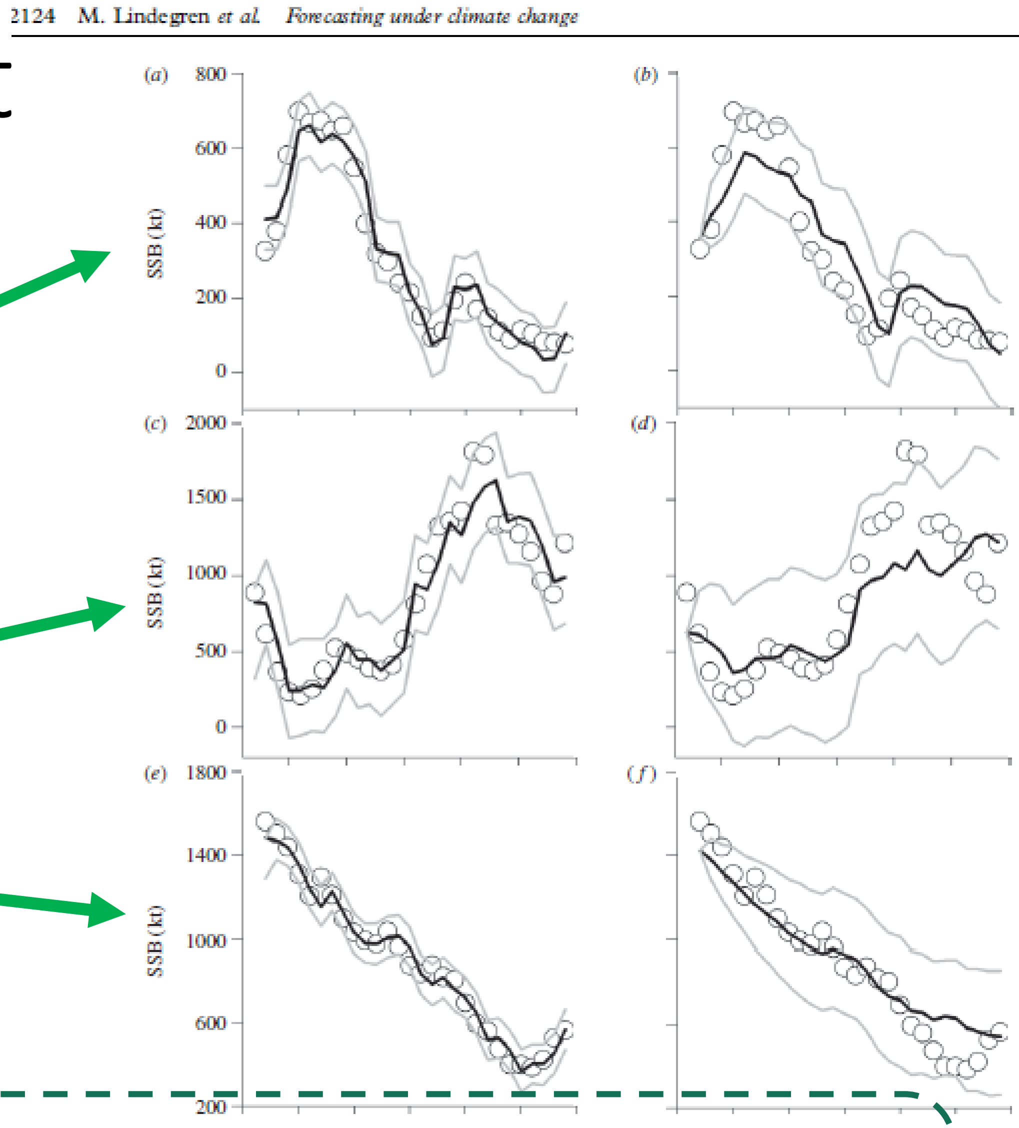
# On the board

- The DM is interested in uncertainty in the event A
- Uncertaninty in A is described using probability $P(A|K)$
- K is the knowledge
- $P(A|K) = P(A|\theta)P(\theta|K)$
- $P(A|\theta)$ ”forecasting”
- $P(\theta|K)$ ”learning”

# Fishery management

Learning



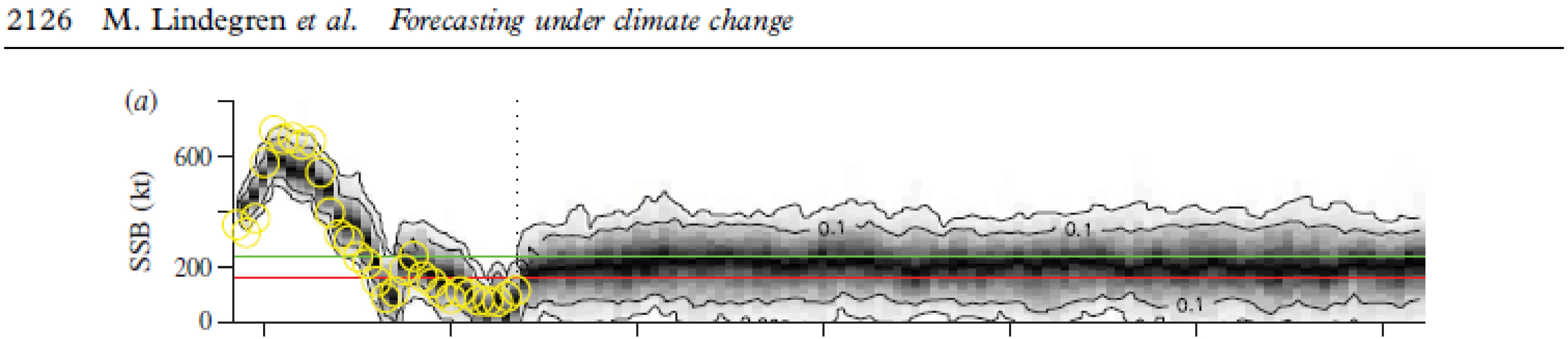




THEORY

EXPERT KNOWLEDGE

DATA

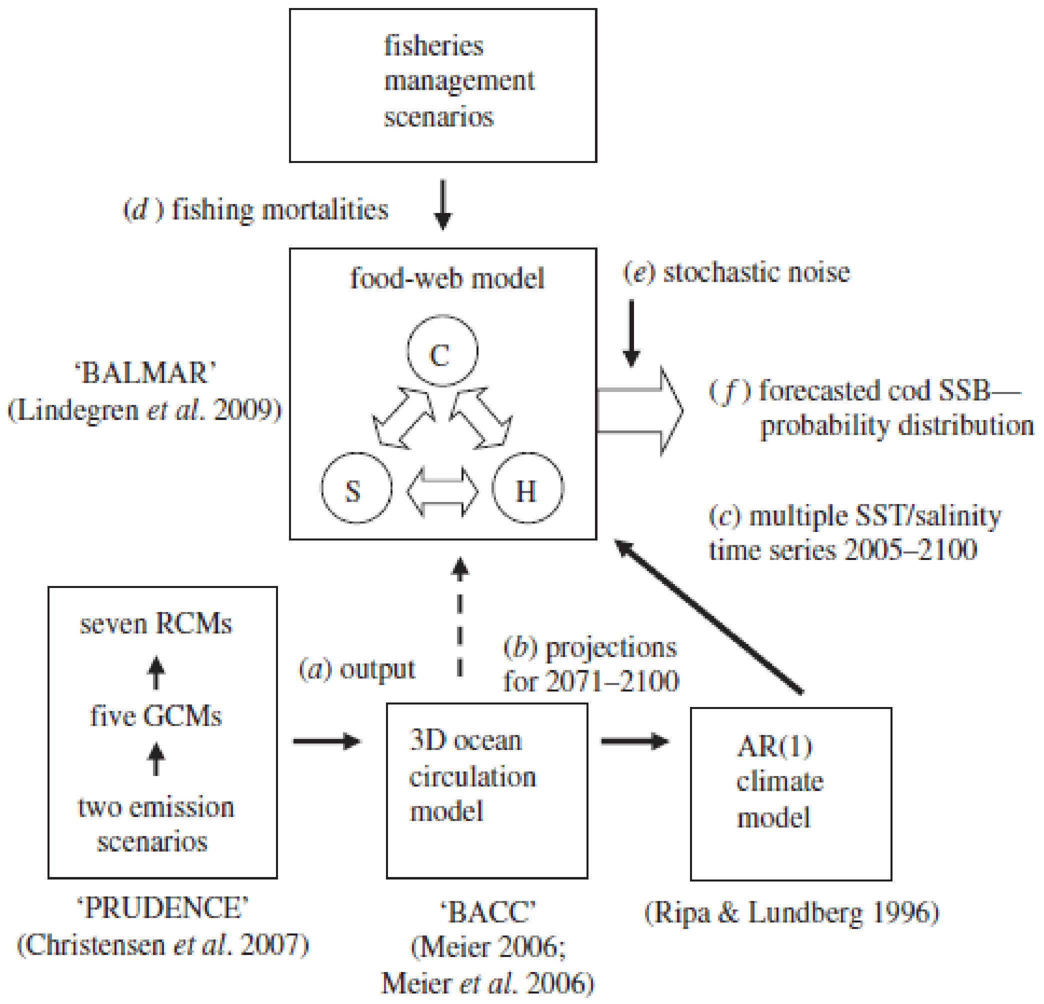
# Fishery managment

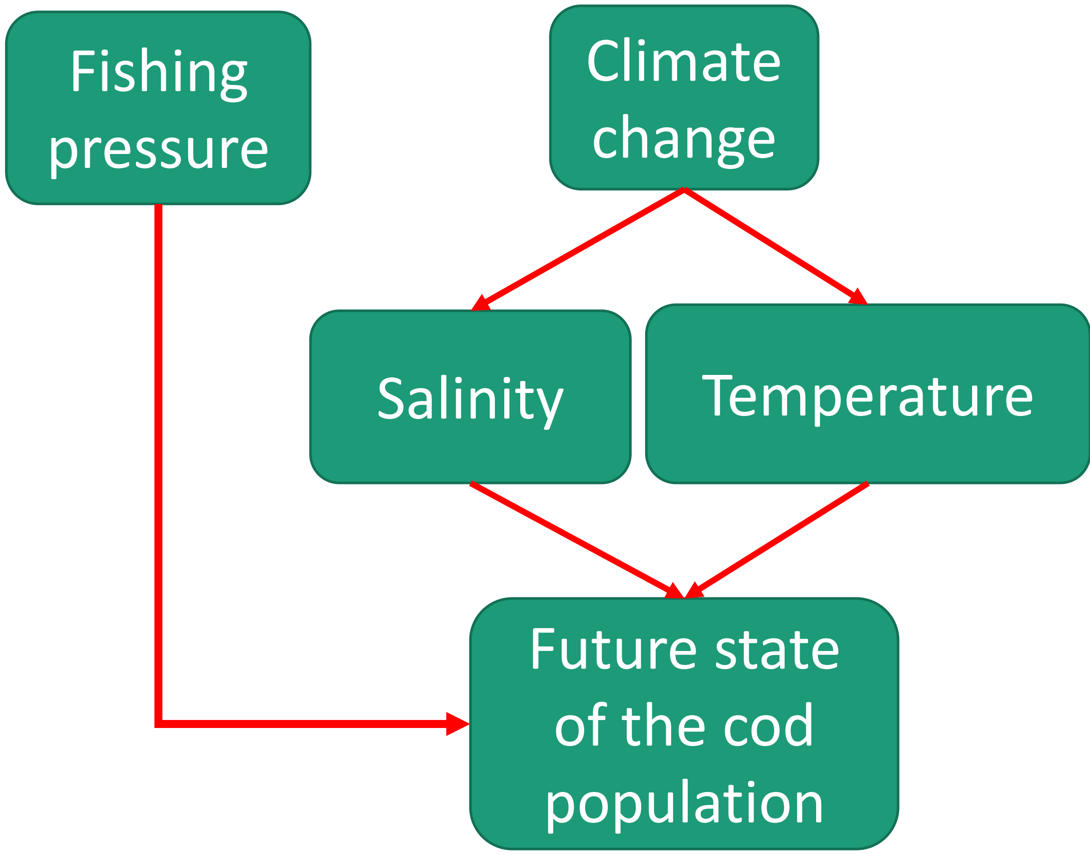


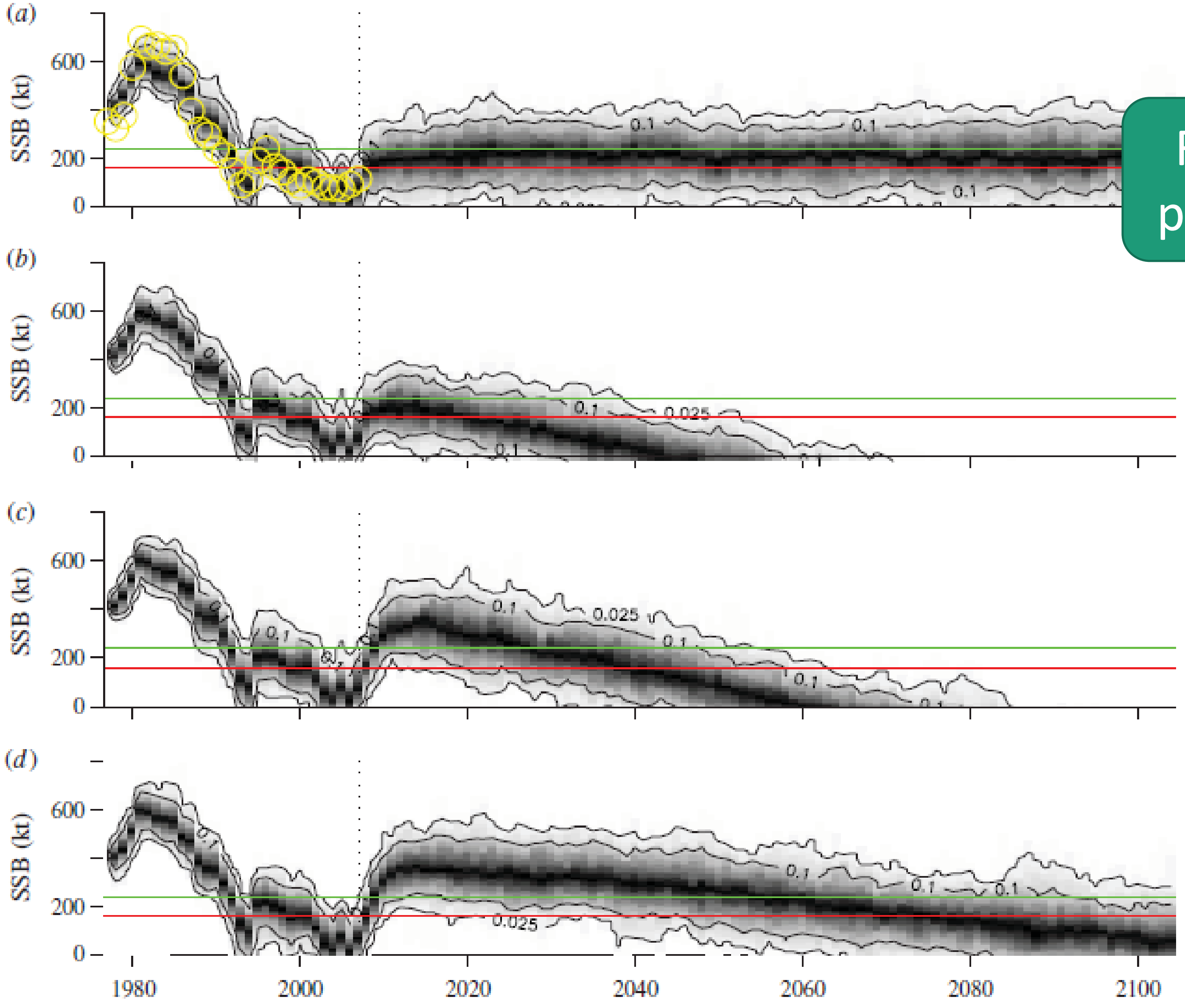

Learning

Forecasting

# Forecasting under climate change

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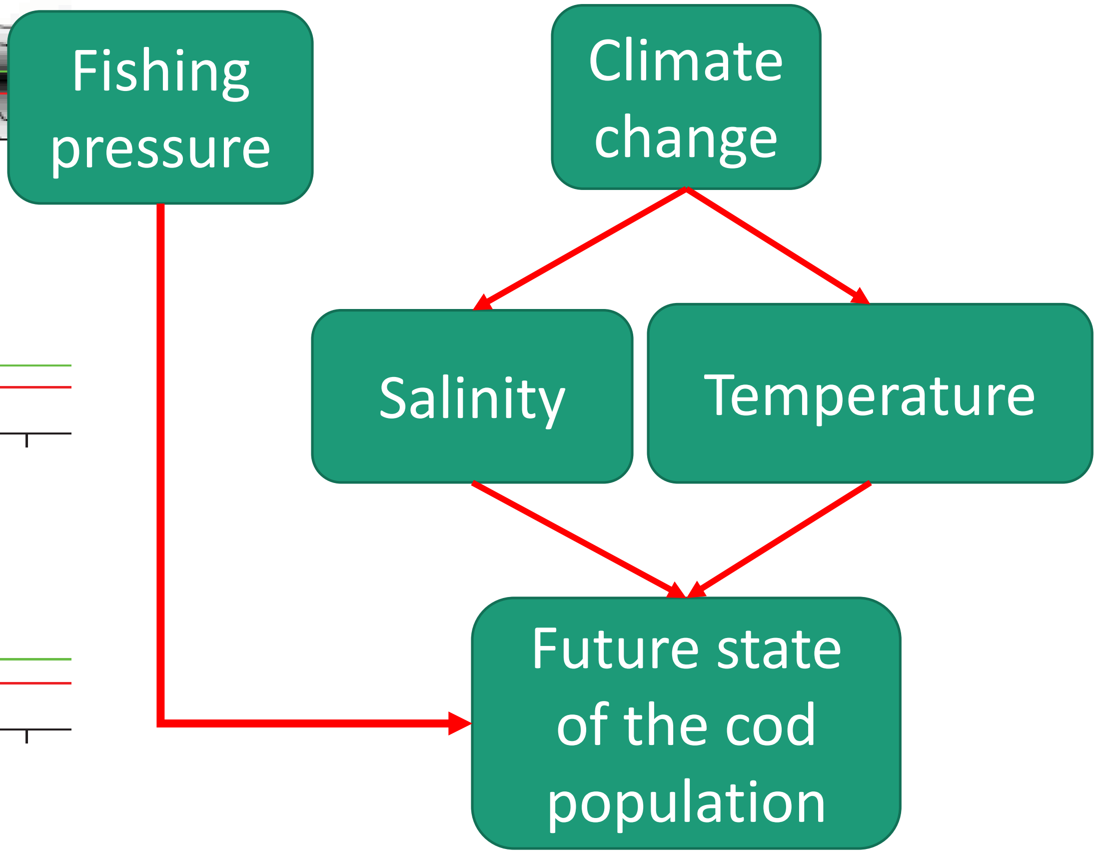
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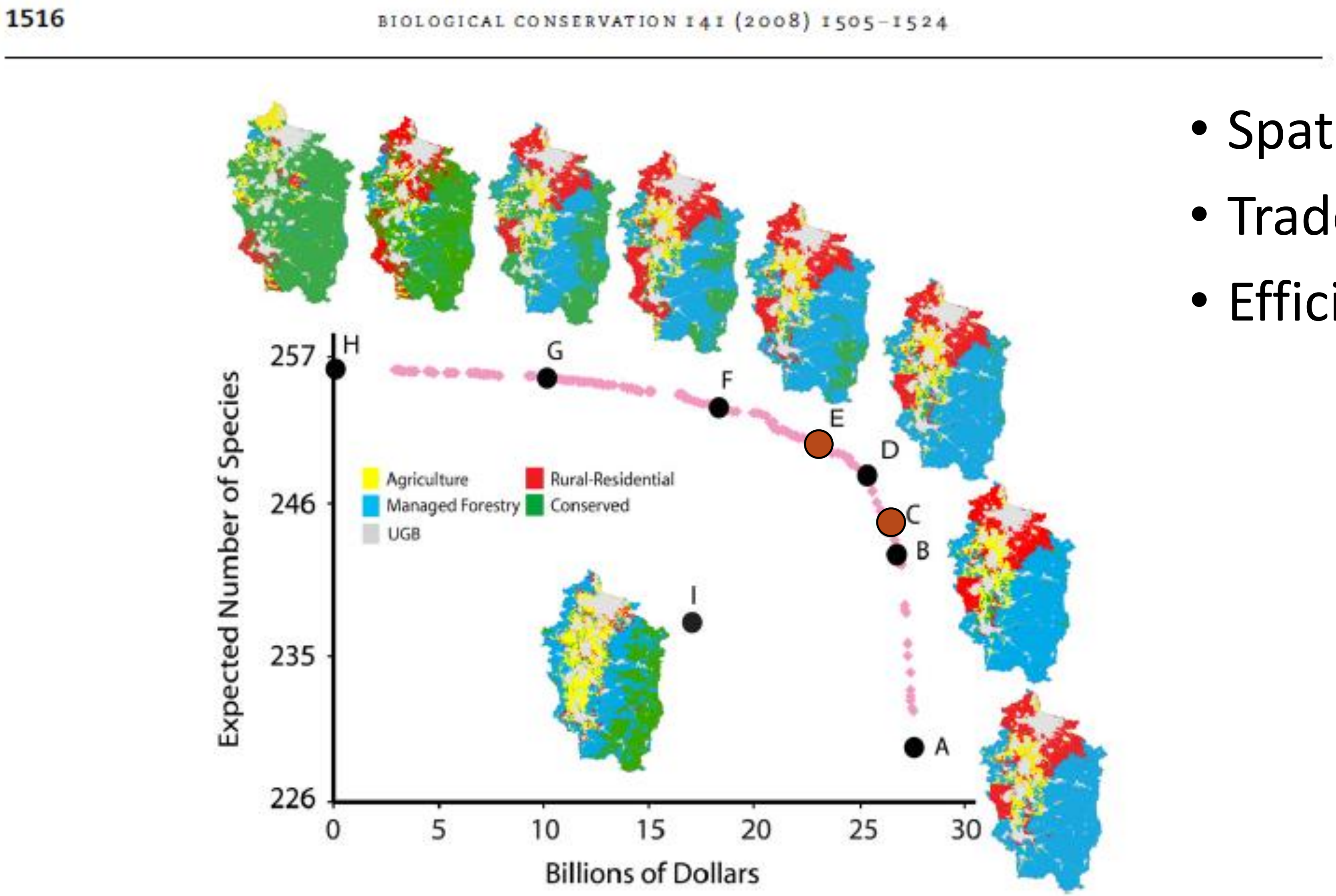
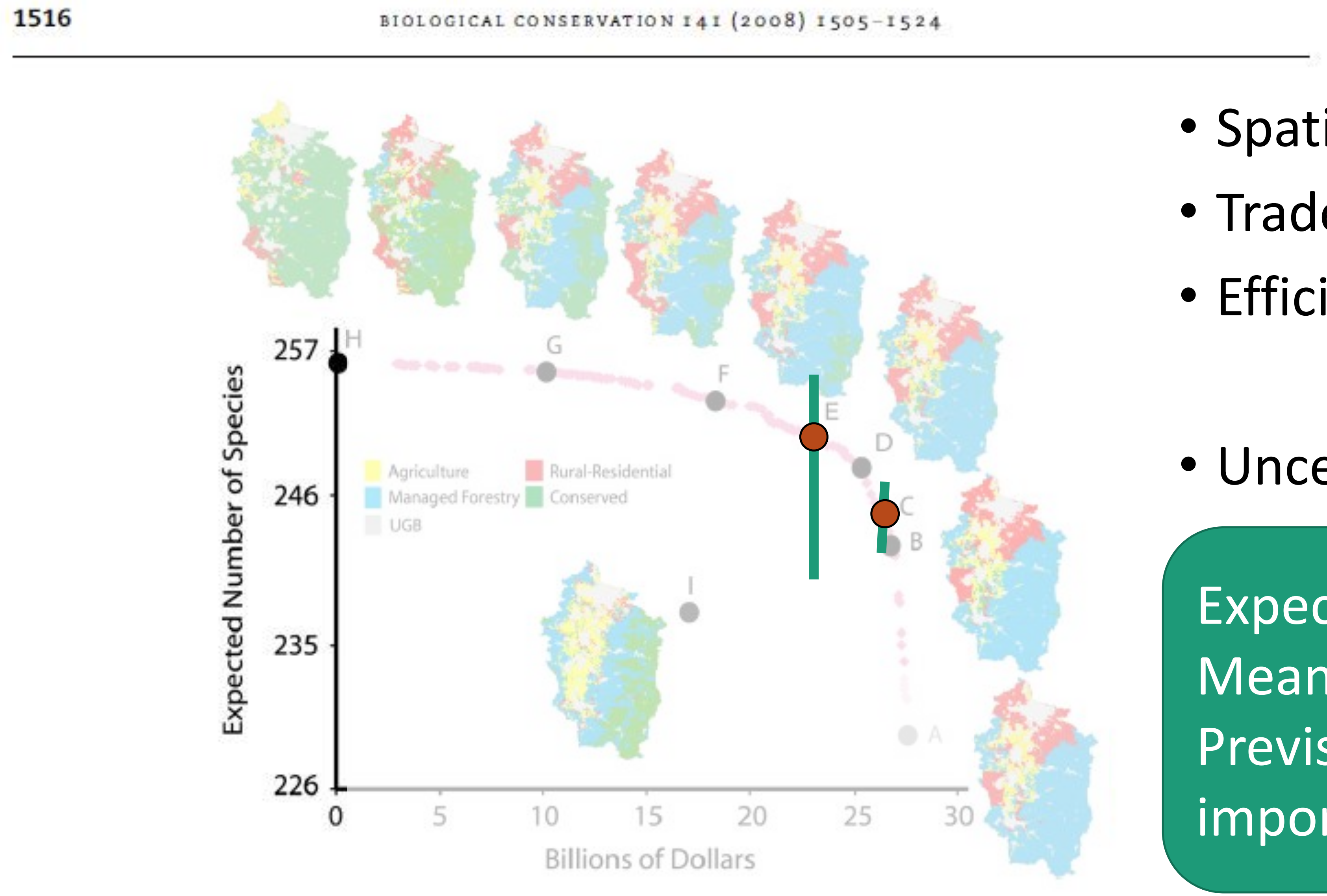
Climate change
Salinity
Temperature
Future state of the cod population

# Biodiversity by land-use management




- Spatial planning
- Trade-offs and synergies
- Efficiency frontiers

# Biodiversity by land-use management




- Spatial planning
- Trade-offs and synergies
- Efficiency frontiers

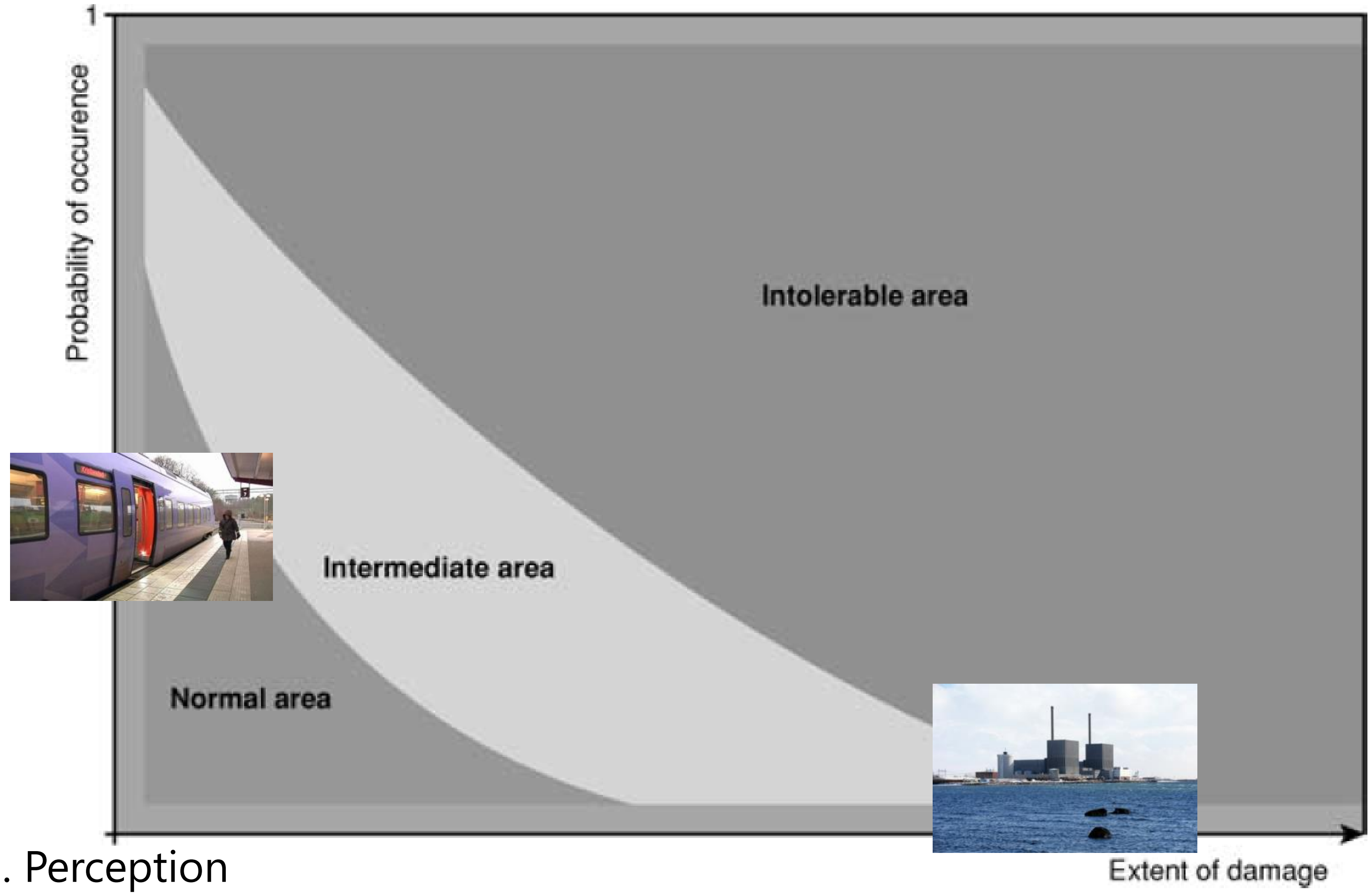
- Uncertainty in outcomes

Expectation:
Mean - a location
Prevision - a quantity important for decisons

# What is an extreme event?

# What is an extreme event?

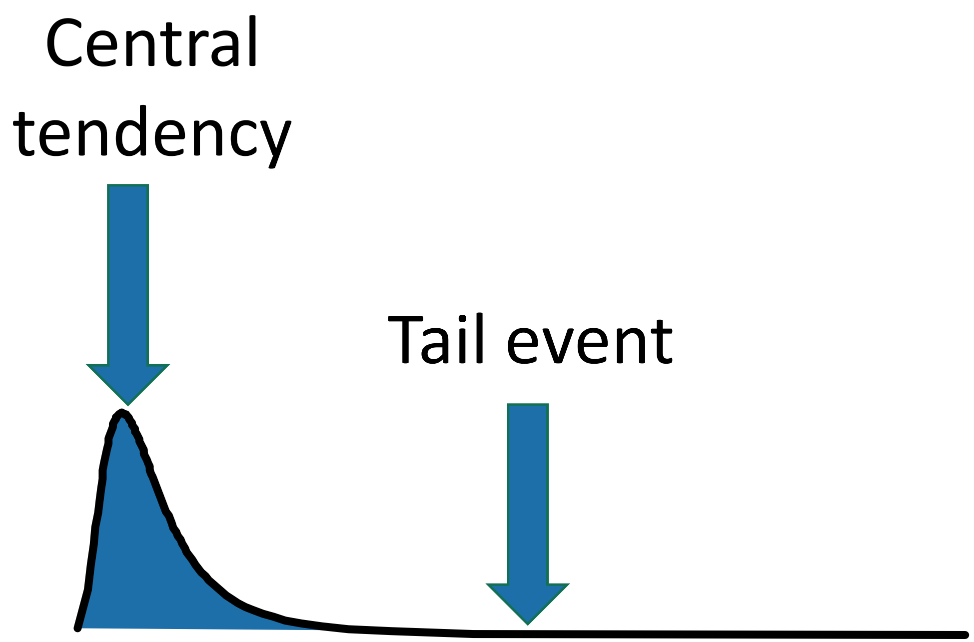
Kaplan and Garrick. 1981. On The Quantitative Definition of Risk. Risk Analysis




Klinke and Renn. 2002. Risk Analysis.

Slovic and Weber. 2002. Perception of risk posed by extreme events.

# What is an extreme event?



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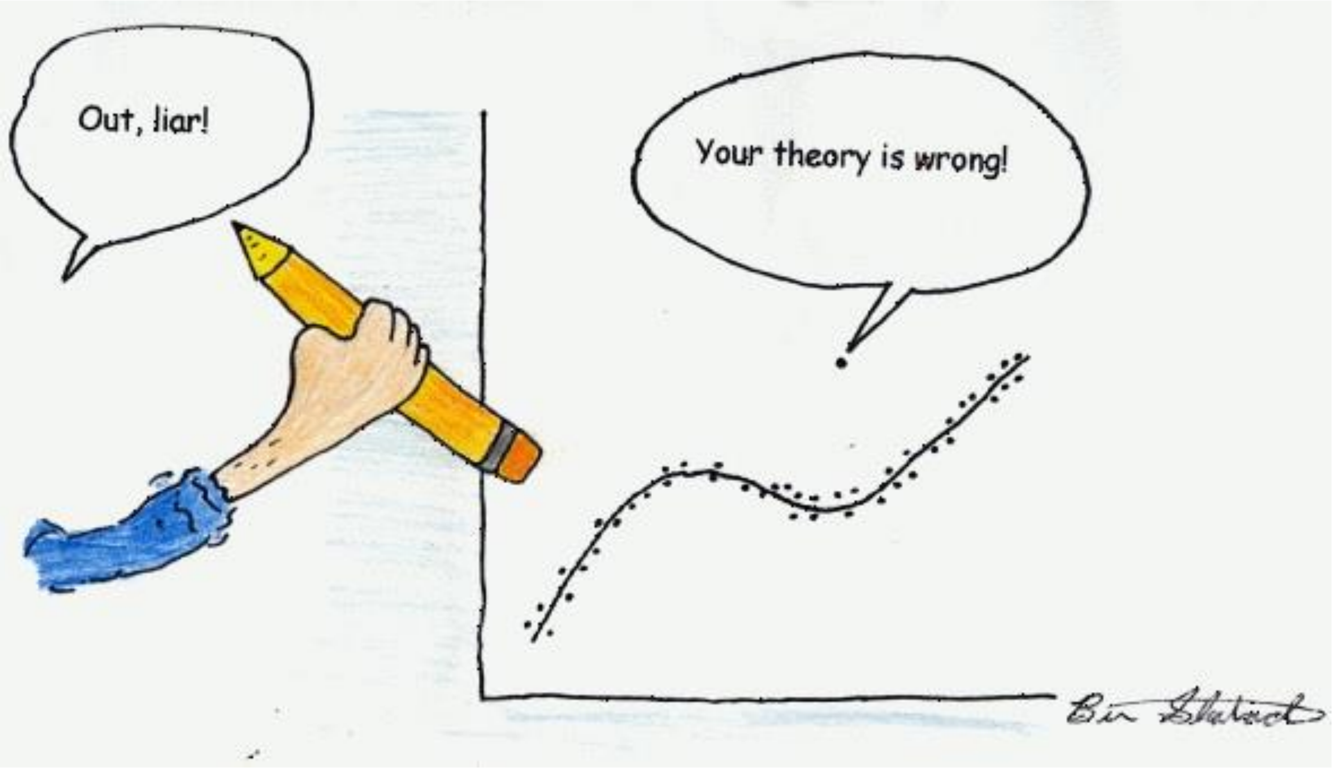



# What is an extreme event

System dimension:

- Unlikely – rare, low frequency
- Large consequence

Knowledge dimension:

- Unlikely – low weight among possible outcomes, surprice in relation to central tendency
- Surprice  – large uncertainy due to lack of knowledge
- Unknown unknown – the unforeseen

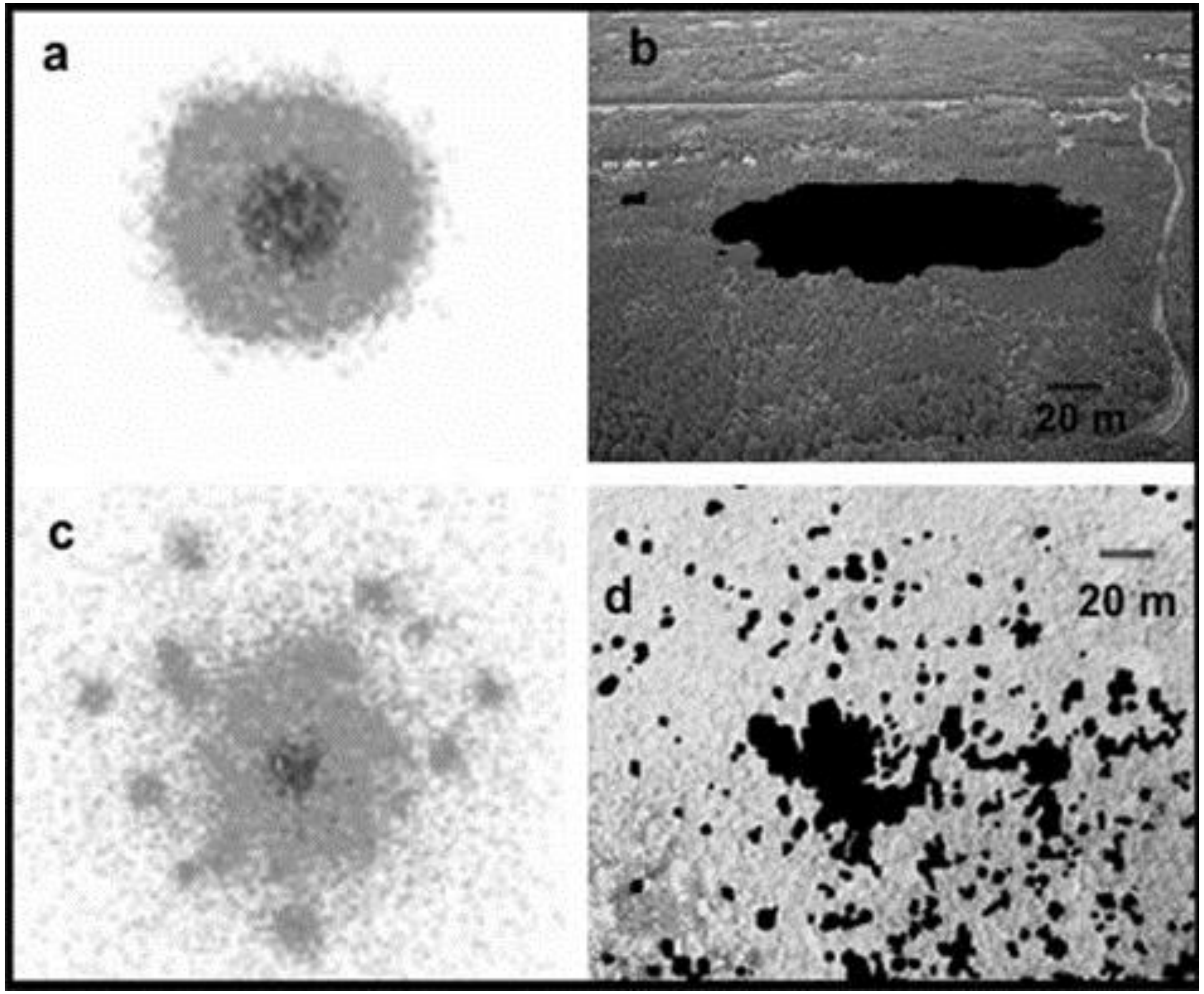
| | |
|---|---|
| Probability-based thinking | P(A\|K) |
| Strength in knowledge | S(K) |
| Surprises (black swans) | K’ |


Taleb, N. 2007. The black swan : the impact of the highly improbable.
Aven, T. 2013. Practical implications of the new risk perspectives. Reliability Engineering & System Safety 115:136-145.

Considering extreme events when Learning & Forecasting is required to make Decisions robust to extreme events

# Include extreme events in modelling

Short and long distance disperal



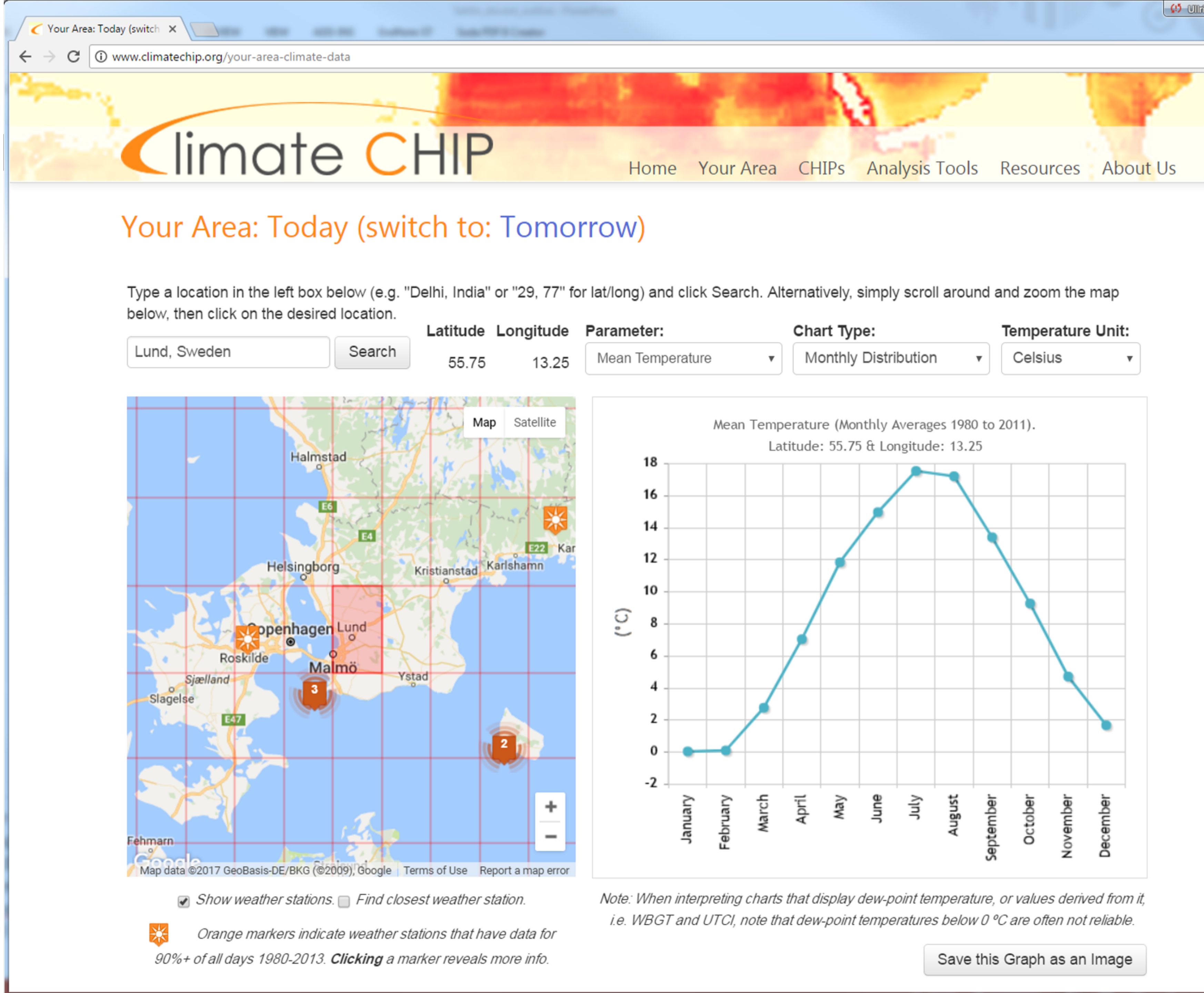

Marco, et al. 2011. Comparing short and long-distance dispersal: modelling and field case studies. Ecography

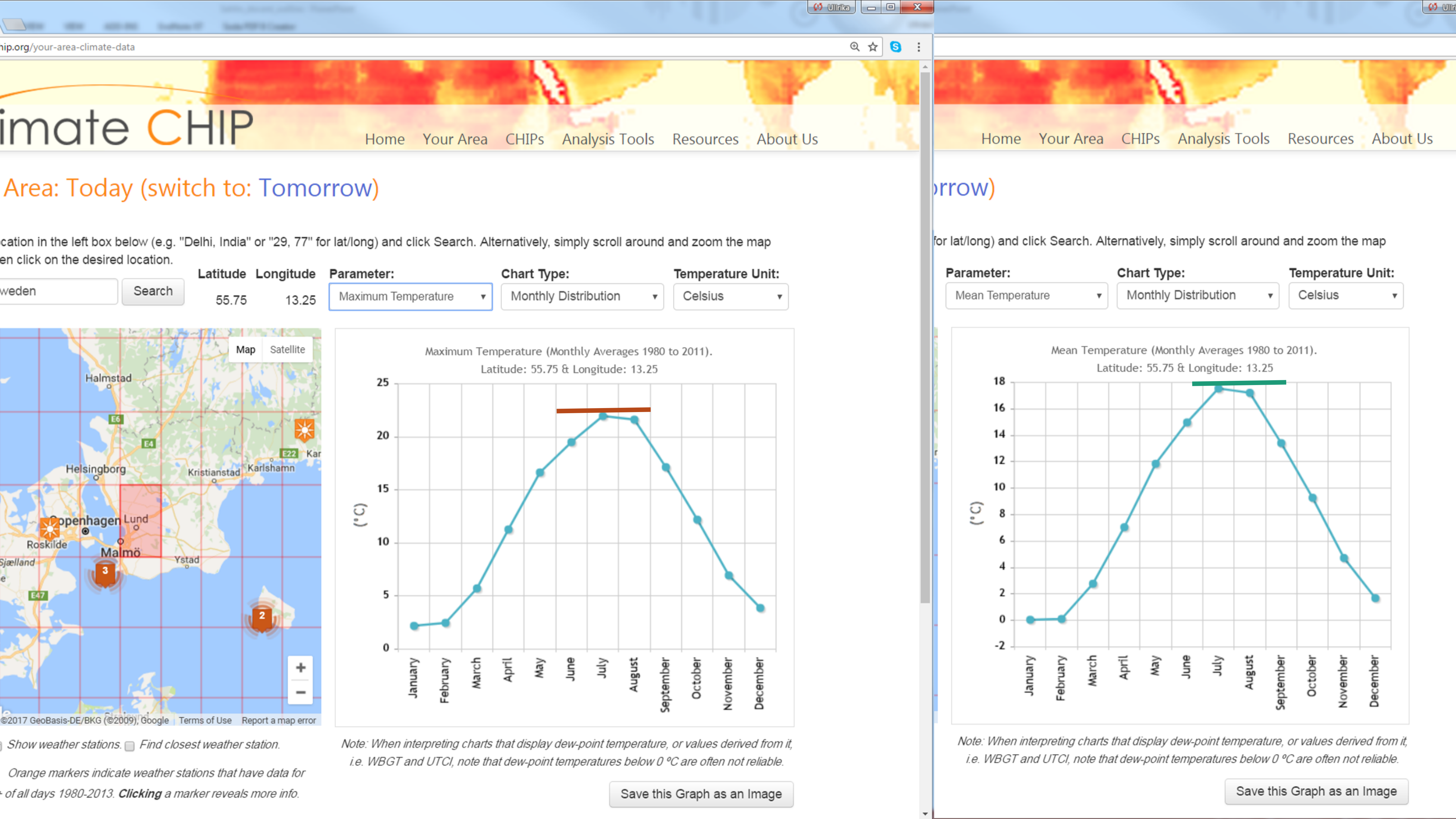
# Include extreme events in modelling

Climate projections

# Include extre

Climate projections

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Show weather stations.
Find closest weather station.
Orange markers indicate weather stations that have data for
of all days 1980-2013. Clicking a marker reveals more info.
Note: When interpreting charts that display dew-point temperature, or values derived from it, i.e. WBGT and UTCI, note that dew-point temperatures below 0 °C are often not reliable.
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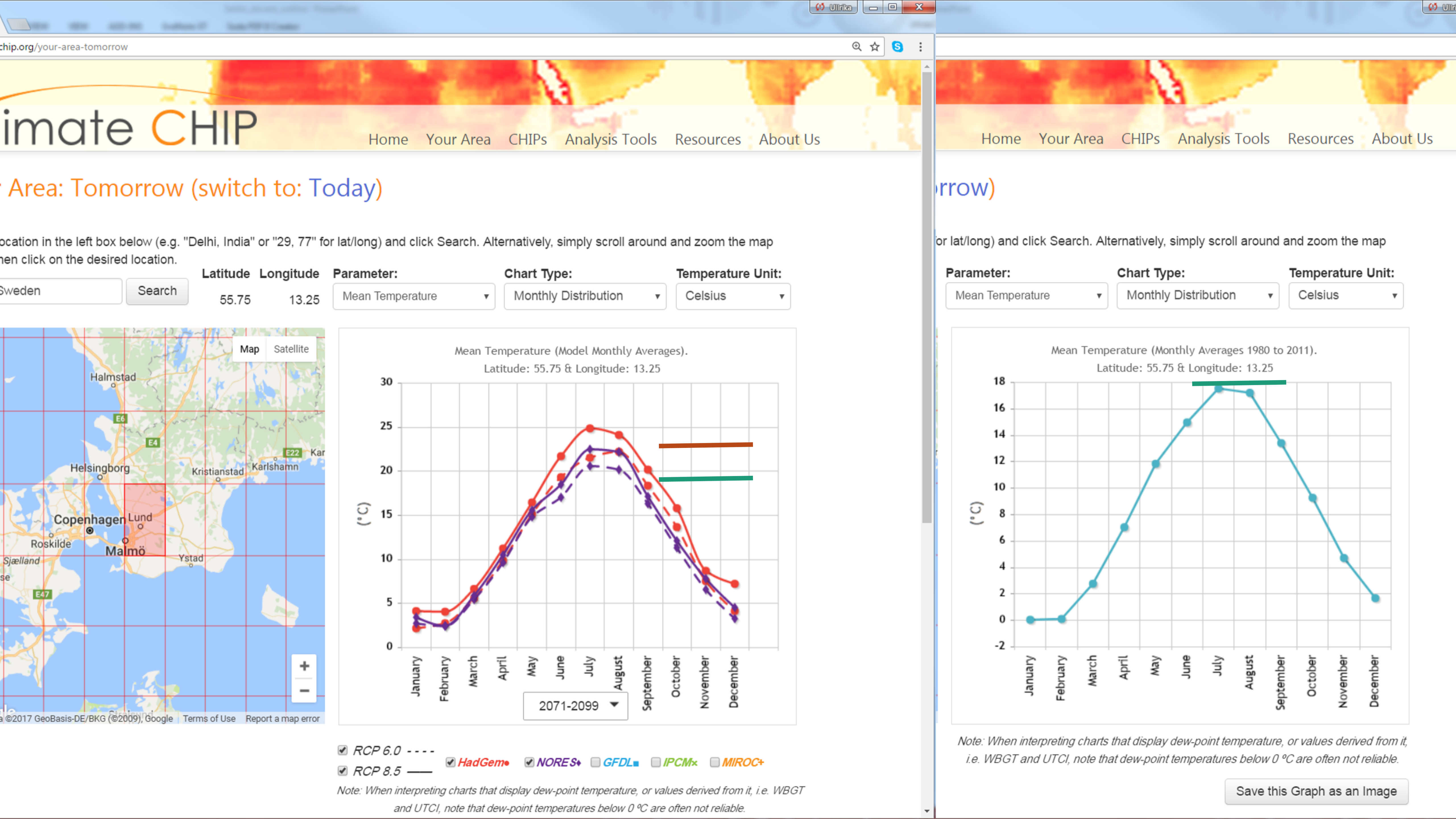
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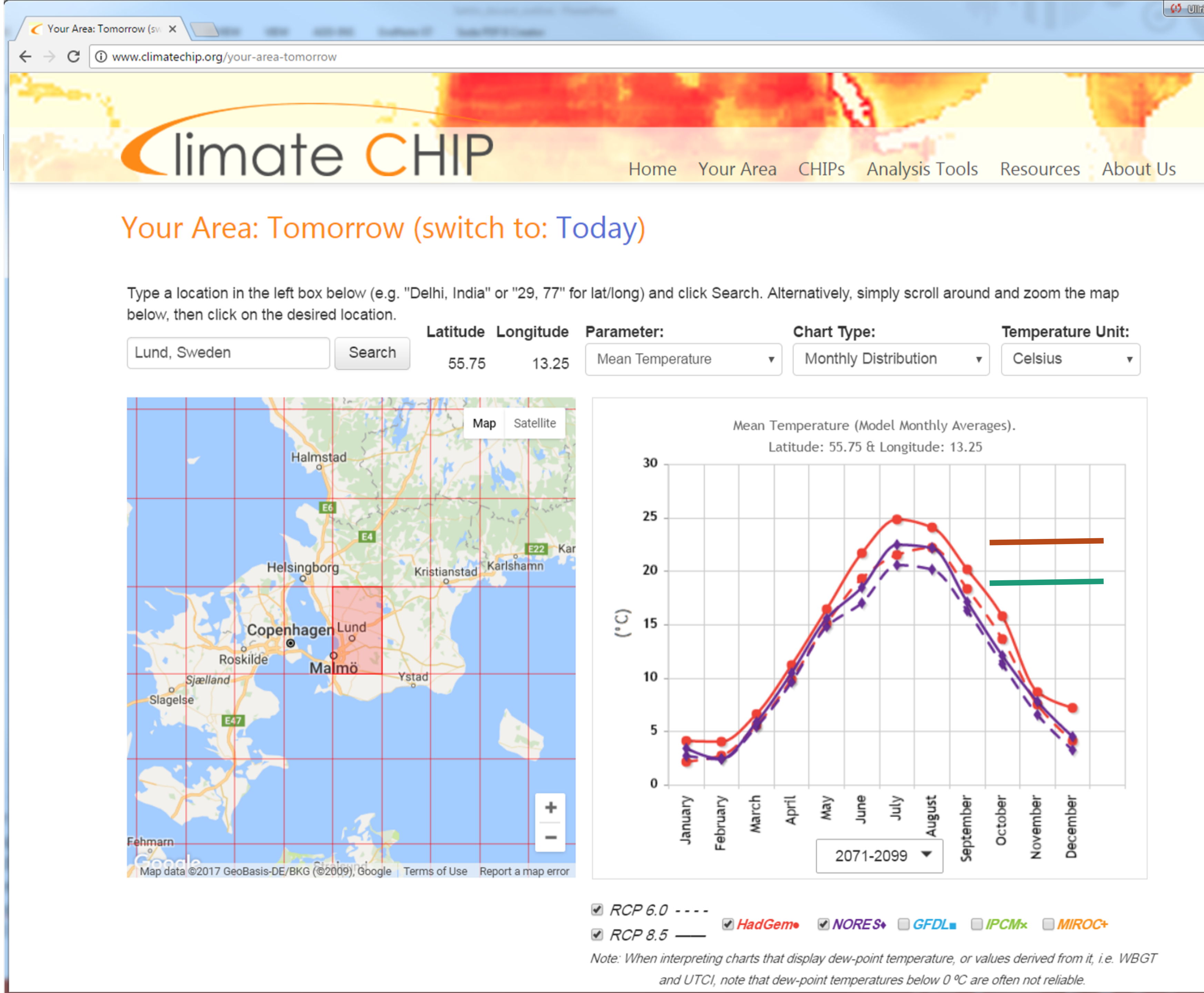
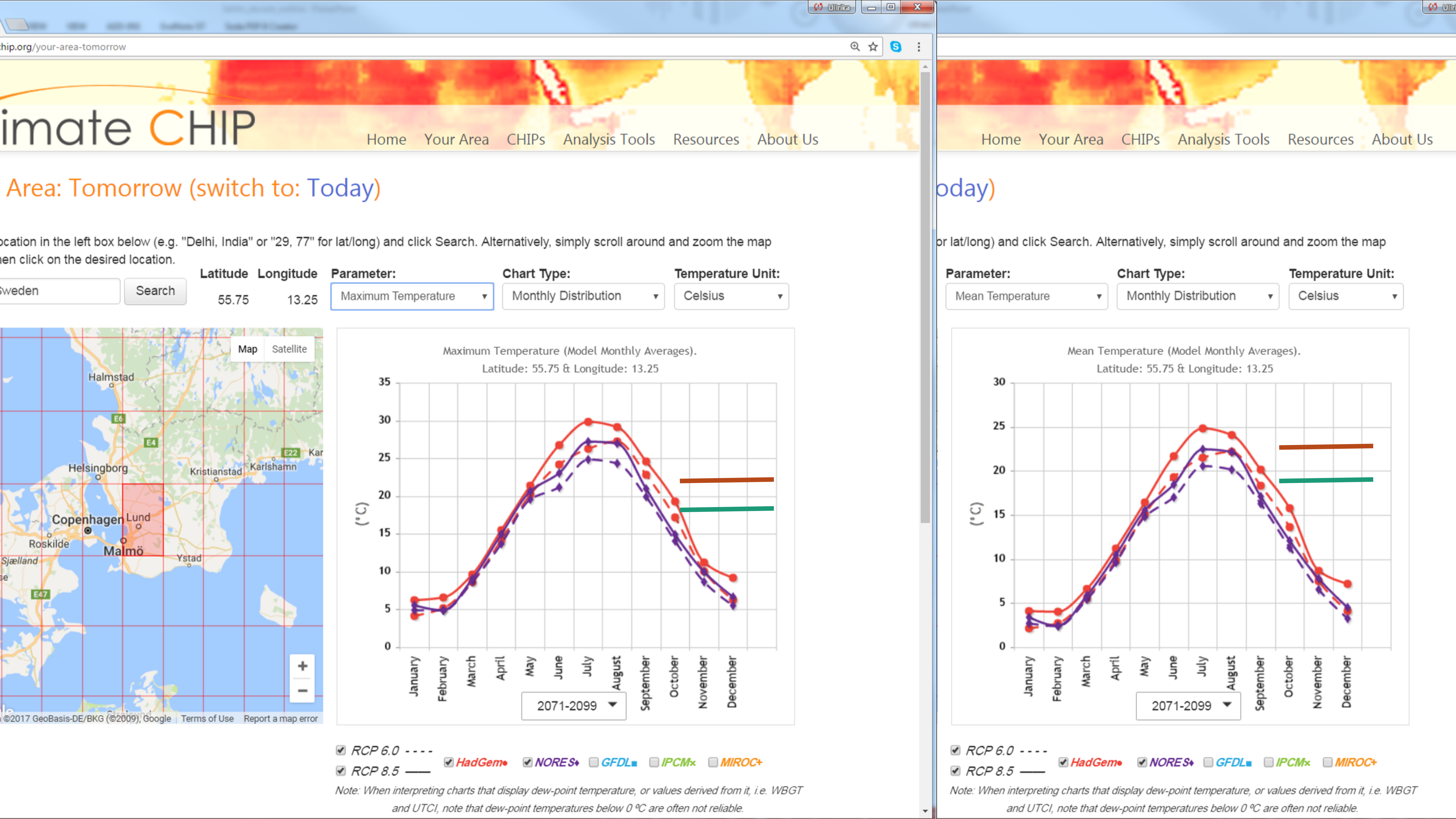
# Include extre

Climate projections





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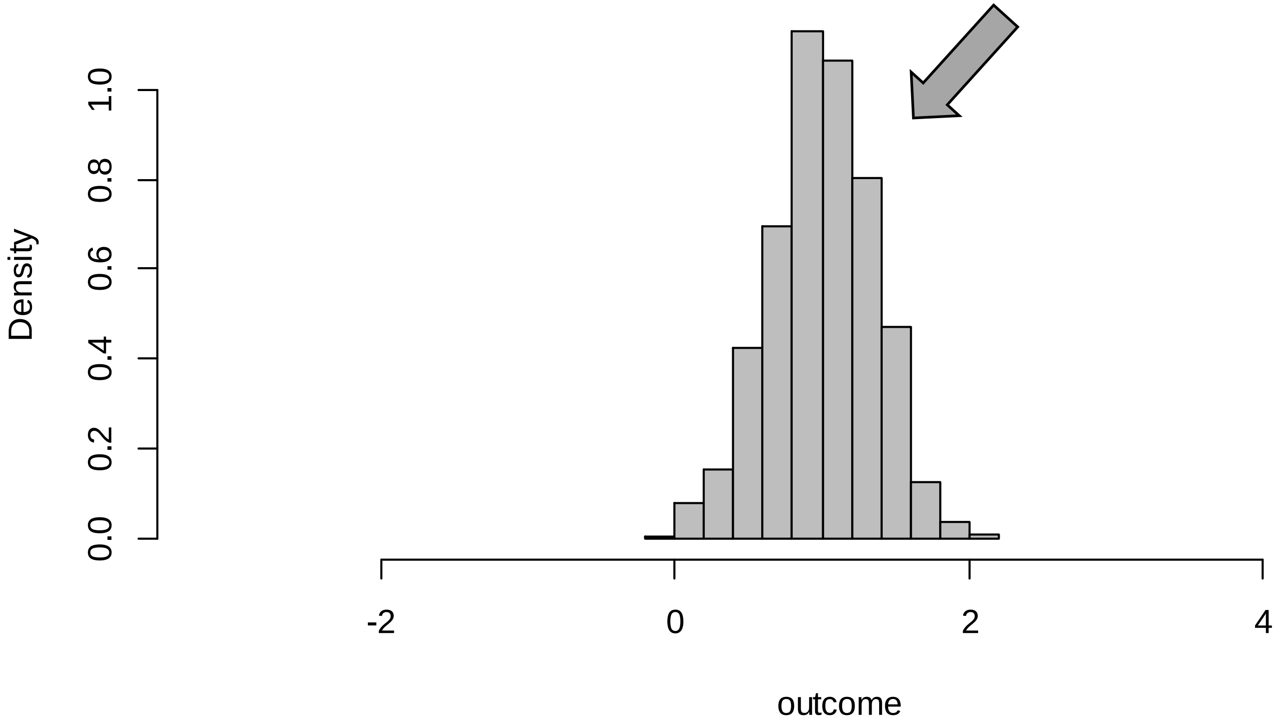
# Use statistical theory for extreme events

Law of large numbers

A sample of sample means is Normally distributed

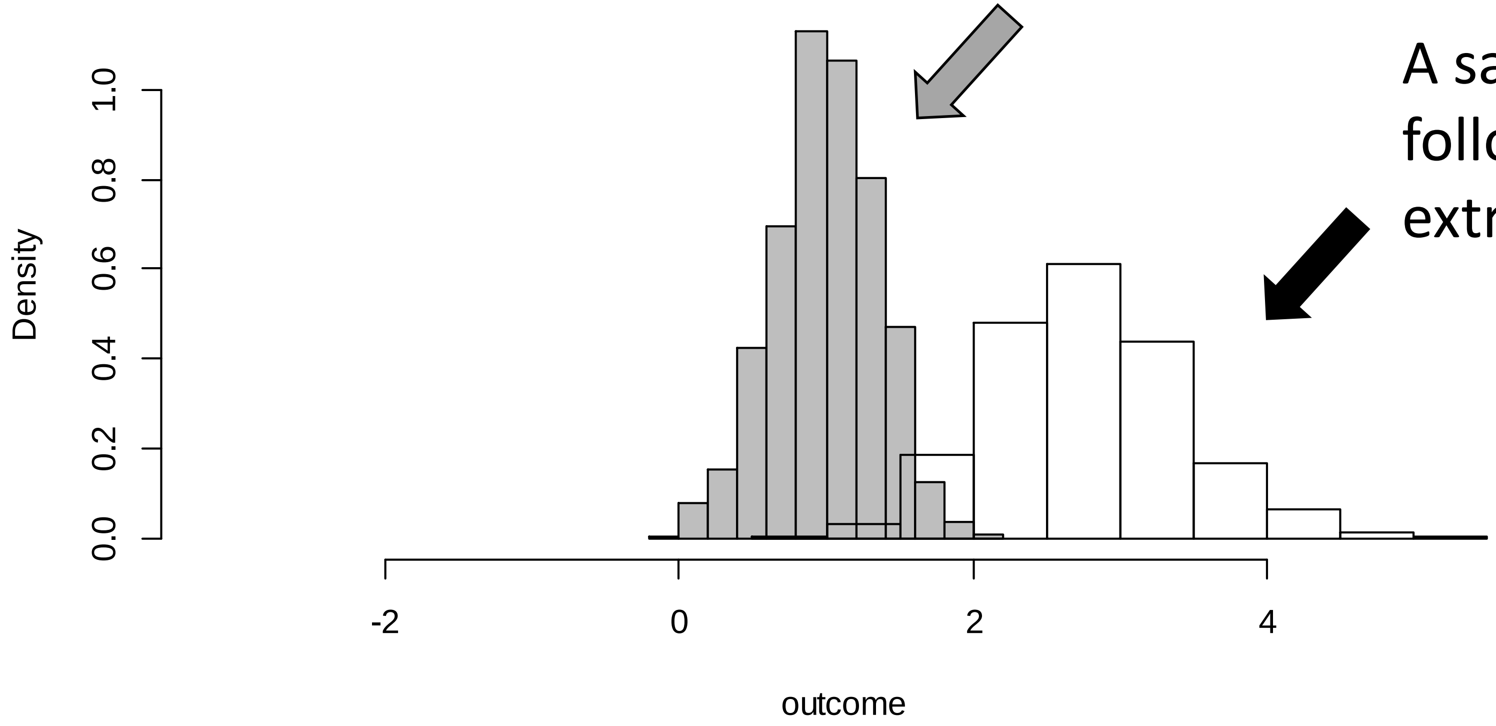


# Use statistical theory for extreme events

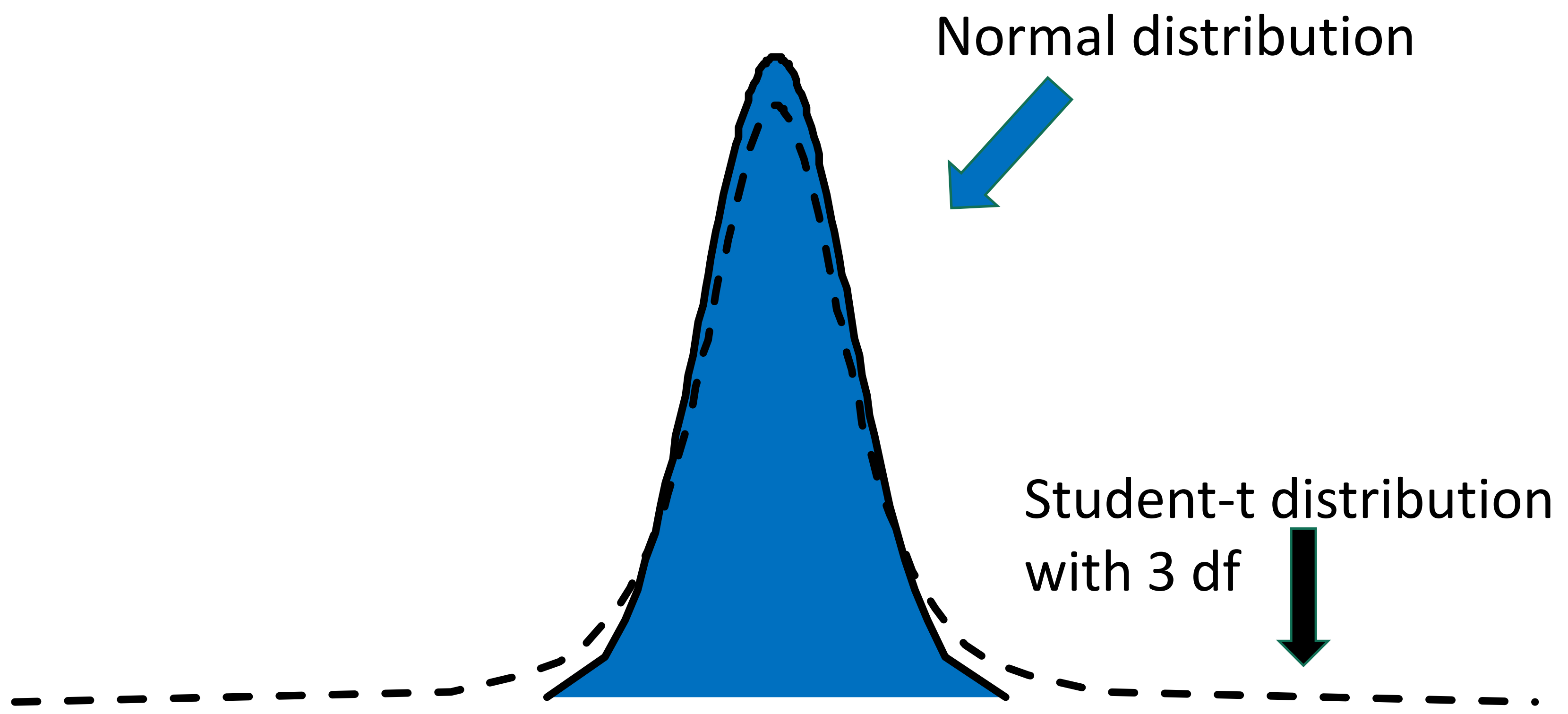
Law of large numbers

A sample of sample means is Normally distributed

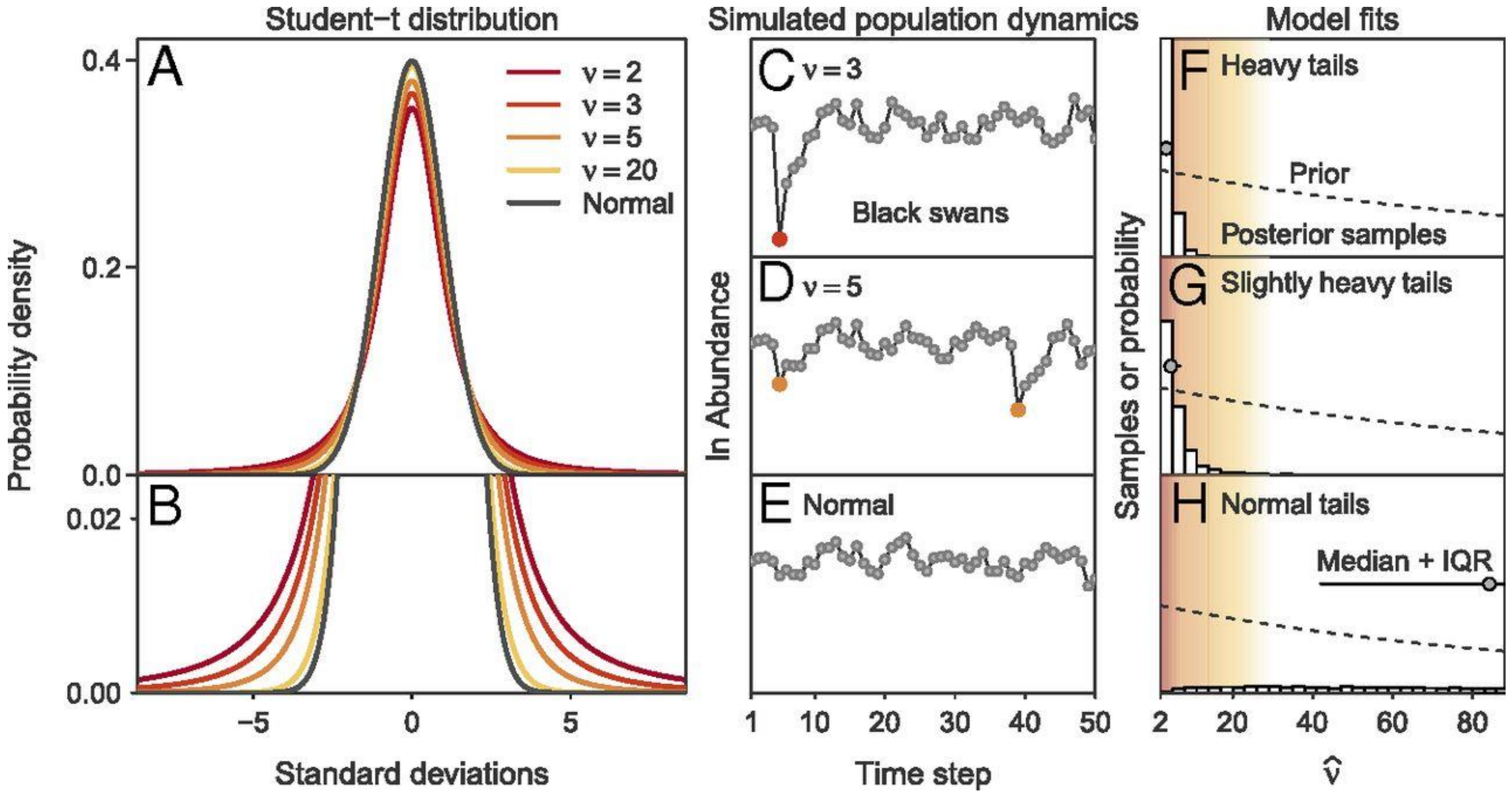
A sample of sample extremes follows a Generalised extreme value distribution



# Include extreme events in random processes



# Illustration of population dynamic models that allow for heavy tails

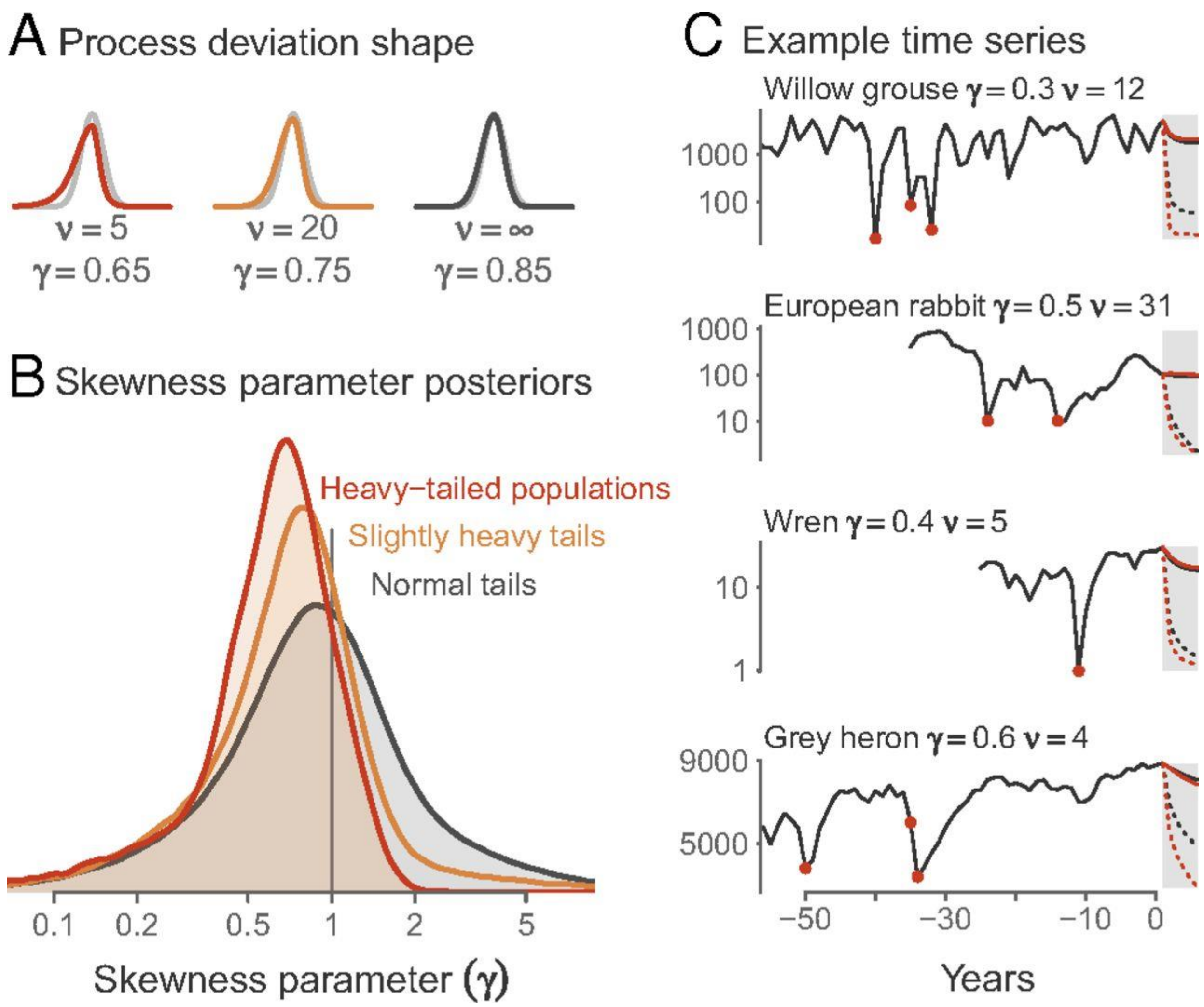



Sean C. Anderson et al. PNAS 2017;114:3252-3257



PNAS

# Ignoring heavy tails can underestimate risk

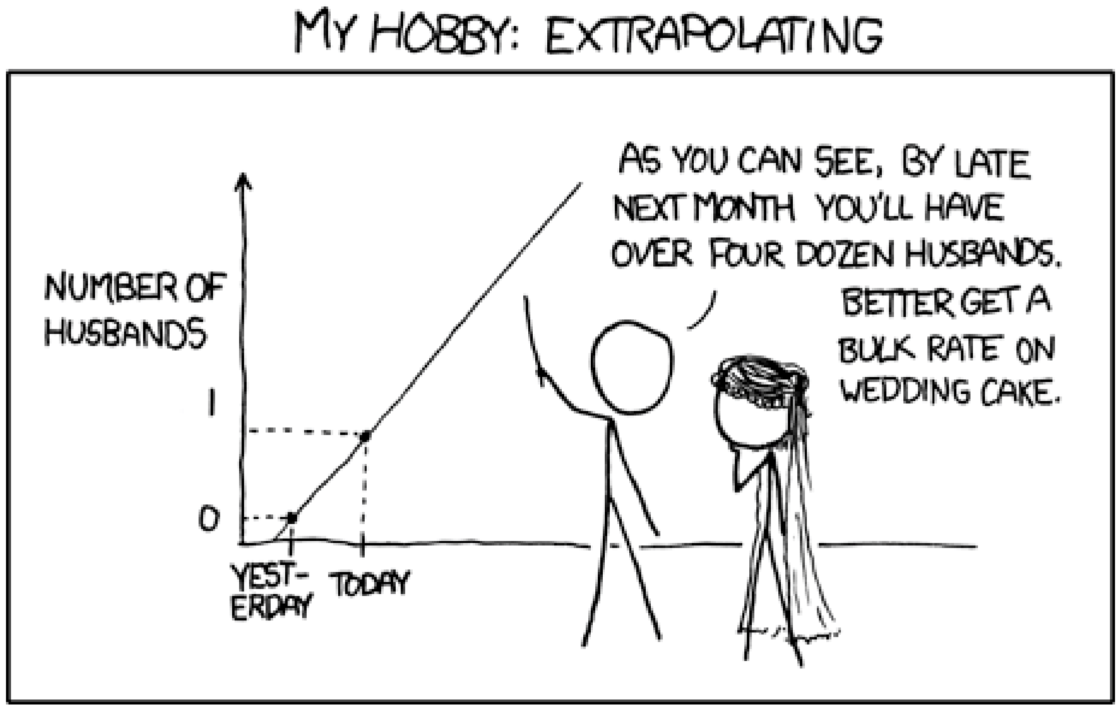



**Sean C. Anderson et al. PNAS 2017;114:3252-3257**

# Our knowledge is seldom ideal to make decisions

Law of ~~large~~ small numbers

*I asked four people in the street and three were happy.*
*75% of people are happy.*




Consdier extreme events in the knowledge dimension

# The number of visitors to this lecture

- Statistical population
  - Sample mean: 24

| 29 | 13 | 10 | 22 | 45 |
|---|---|---|---|---|
| | | | | |
| | | | | |

# The number of visitors to this lecture

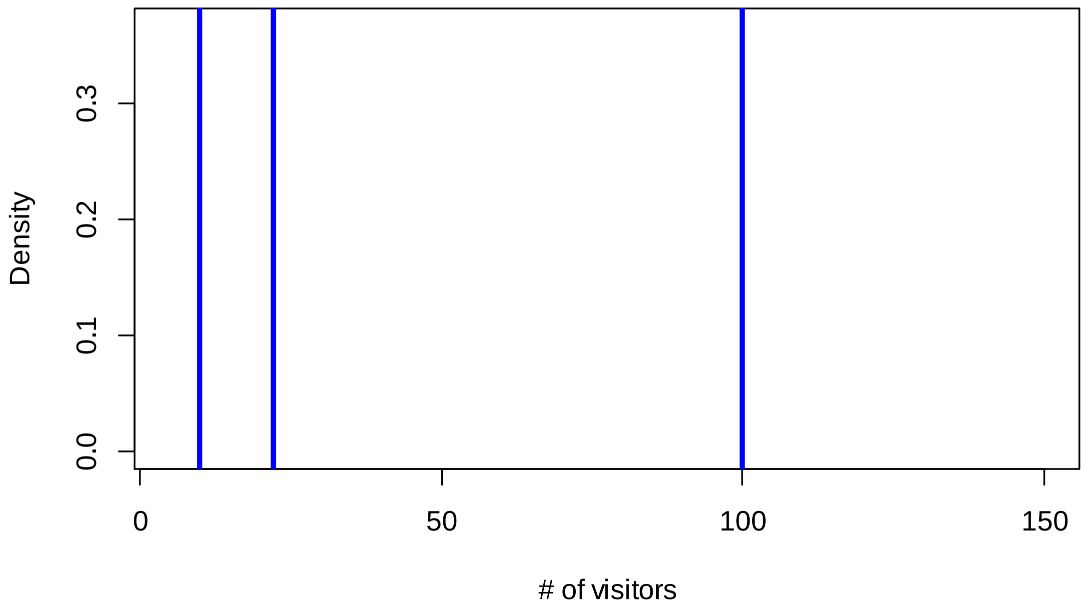
- Statistical population
  - Sample mean: 24
- Analogy prediction
  - Friday & Maths: 13

| 29 | 13 | 10 | 22 | 45 |
|---|---|---|---|---|
| Birds | Maths | Birds | Maths | Birds |
| Friday | Friday | Tuesday | Tuesday | Tuesday |

# The number of visitors to this lecture

- Statistical population
  - Sample mean: 24
- Analogy prediction
  - Friday & Maths: 13
- Just guess
  - Lower value: 10
  - Higher value: 100
  - Most likely value: 22

| 29 | 13 | 10 | 22 | 45 |
|---|---|---|---|---|
| Birds | Maths | Birds | Maths | Birds |
| Friday | Friday | Tuesday | Tuesday | Tuesday |

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- Statistical population
  - Sample mean: 24
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- Just guess
  - Lower value: 10
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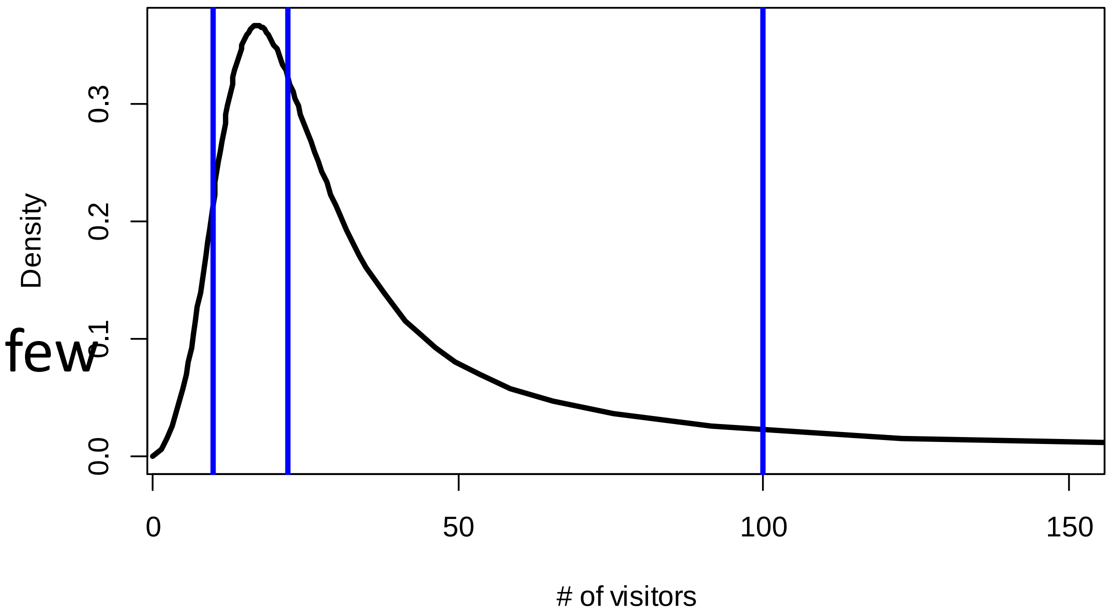
  - Most likely value: 22
  - 1% chance 200 sets are too few

| **29** | **13** | **10** | **22** | **45** |
|---|---|---|---|---|
| Birds | Maths | Birds | Maths | Birds |
| Friday | Friday | Tuesday | Tuesday | Tuesday |

LogT(2.84,0.578)

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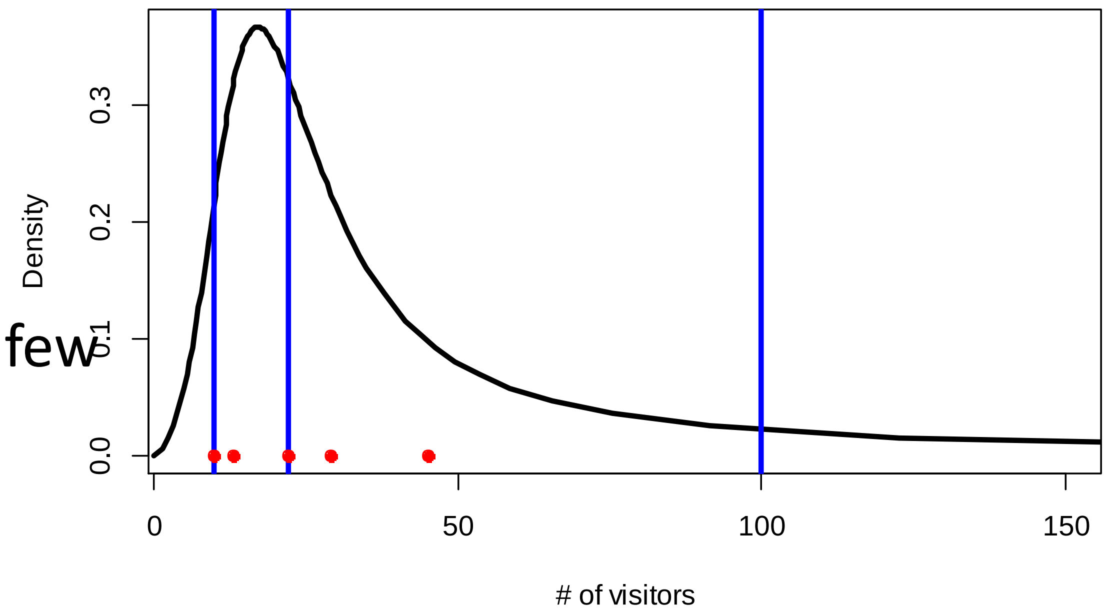

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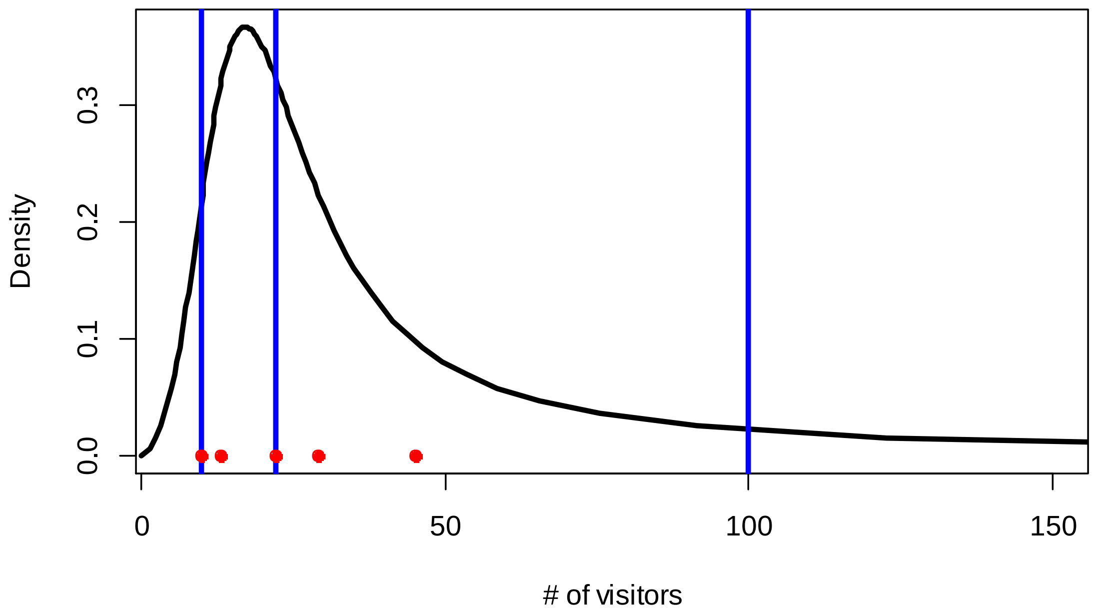


Relative frequency ↔ Personal probability

Relative frequency ⟷ Personal probability

# Different types of uncertainty

**Irreducable uncertainty**

- Variability
- Inherent randomness
- Stochasticity
- Aleatory uncertainty

**Reducable uncertainty**

- Lack of knowledge
- Ignorance
- Incertitude
- Epistemic uncertainty

Relative frequency ⟷ Personal probability

# Different types of uncertainty

**Decision making under risk**

- Maximise prevision taken over a relative frequency
- Risk aversion

**Decision making under uncertainty**

- Maximise prevision taken over probability representing our believes (personal probability)
- Cautionary principles

**Decision making under deep uncertainty**

- Apply robust decision criteria
- Adapt management
- Precautionary principle

# Different types of uncertainty

**Decision making under risk**

**Decision making under uncertainty**

**Decision making under deep uncertainty**

Strength in knoweldge

# Assess strenght in knowledge

Strength in knoweldge

**Table 2:** Example of quality indicators for scientific evidence (after Bowden, 2004).

| Quality rank | Indicators of evidence quality | | | | | |
|---|---|---|---|---|---|---|
| | **Theoretical basis** | **Scientific method** | **Auditability** | **Calibration** | **Calibration** | **Objectivity** |
| **Very high** | Well established theory | Best available practice: large sample; direct measure | Well documented trace to data | An exact fit to data | Independent measurement of sample variable | No discernable bias |
| **High** | Accepted theory; high degree of consensus | Accepted reliable method; small sample; direct measure | Poor documented but traceable to data | Good fit to data | Independent measurement of high correlation variable | Weak bias |
| **Moderate** | Accepted theory; low consensus | Accepted method; derived or surrogate data; analogue; limited reliability | Traceable to data with difficulty | Moderately well correlated with data | Validation measure not truly independent | Moderate bias |
| **Low** | Preliminary theory | Preliminary method of unknown reliability | Weak and obscure link to data | Weak correlation to data | Weak indirect validation | Strong bias |
| **Very low** | Crude speculation | No discernable rigour | No link back to data | No apparent correlation | No validation presented | Obvious bias |

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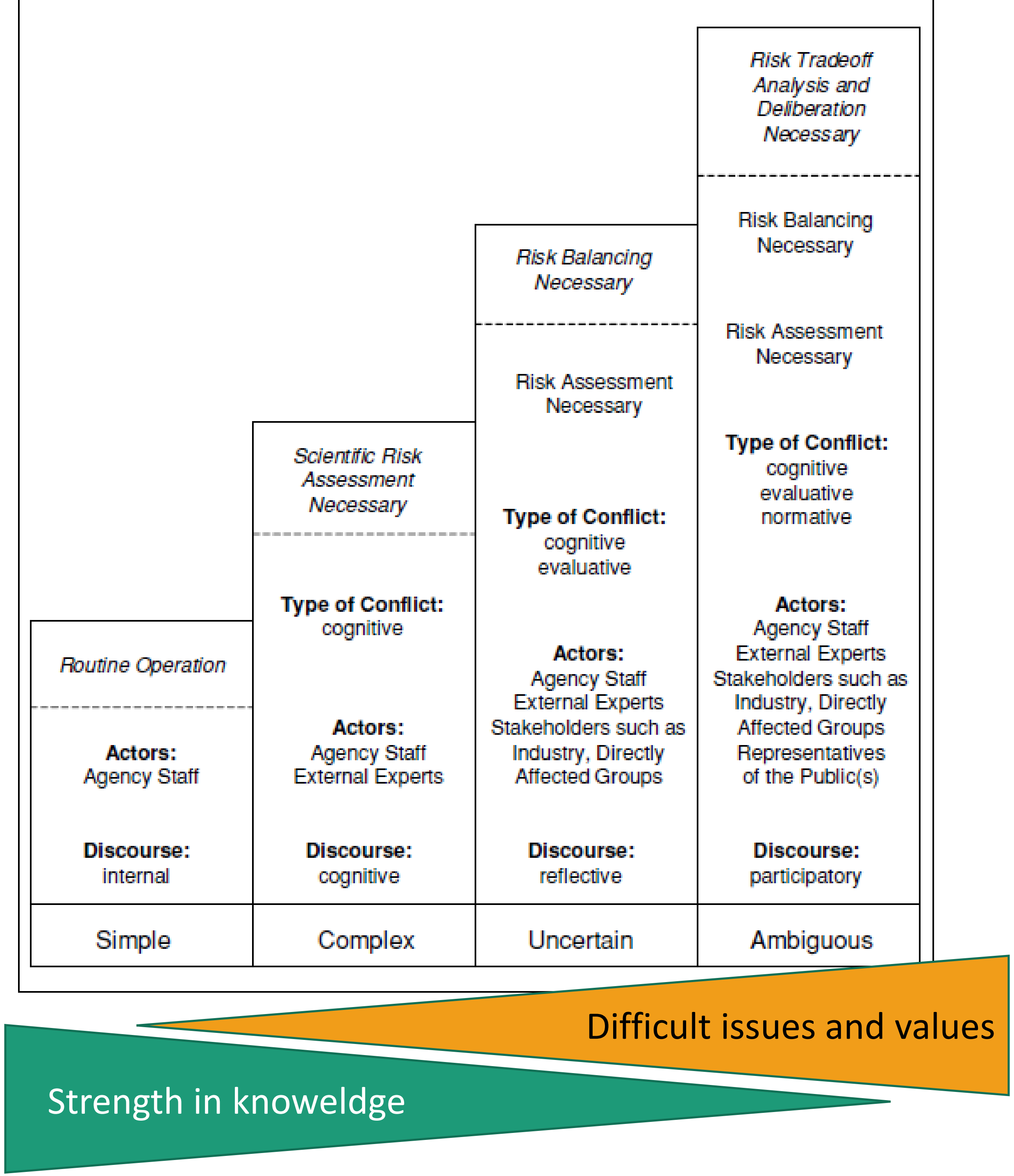
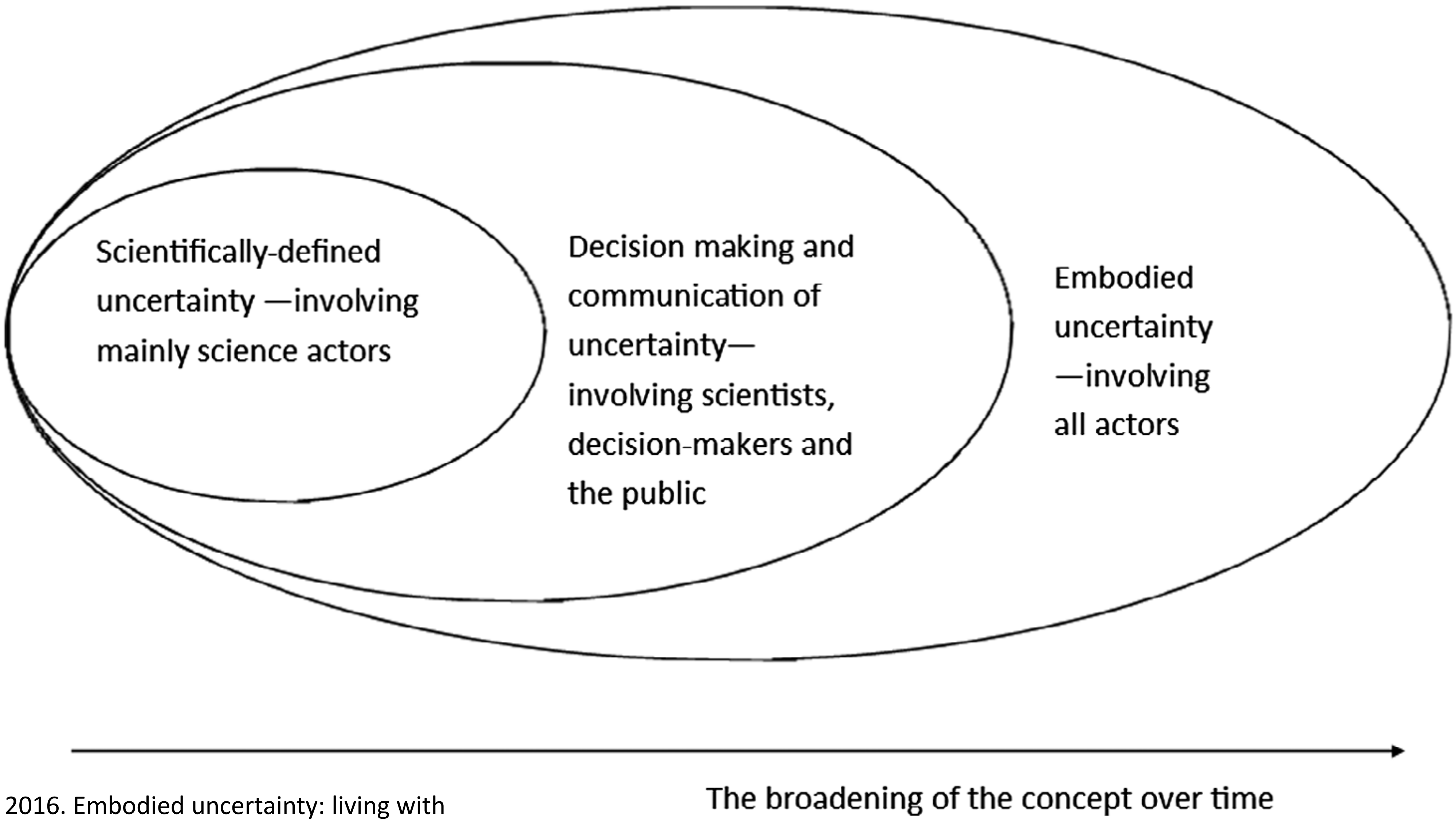
# Adapt management

Klinke and Renn. 2002. A new approach to risk evaluation and management: Risk-based, precaution-based, and discourse-based strategies. Risk Analysis.

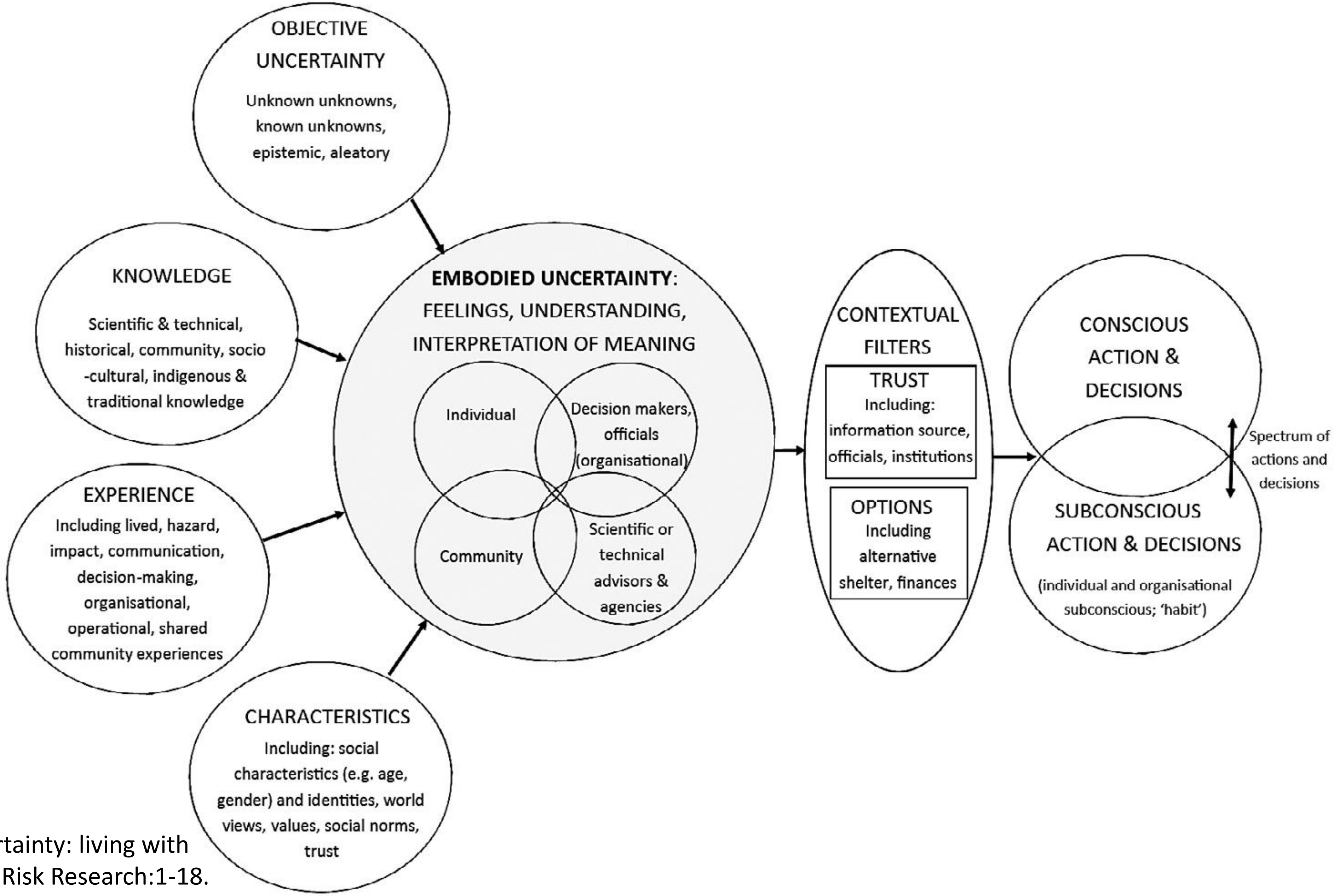


# Broaden the uncertainty concept




Sword-Daniels et al. 2016. Embodied uncertainty: living with complexity and natural hazards. Journal of Risk Research:1-18.

# Broaden the uncertainty concept




Sword-Daniels et al. 2016. Embodied uncertainty: living with complexity and natural hazards. Journal of Risk Research:1-18.

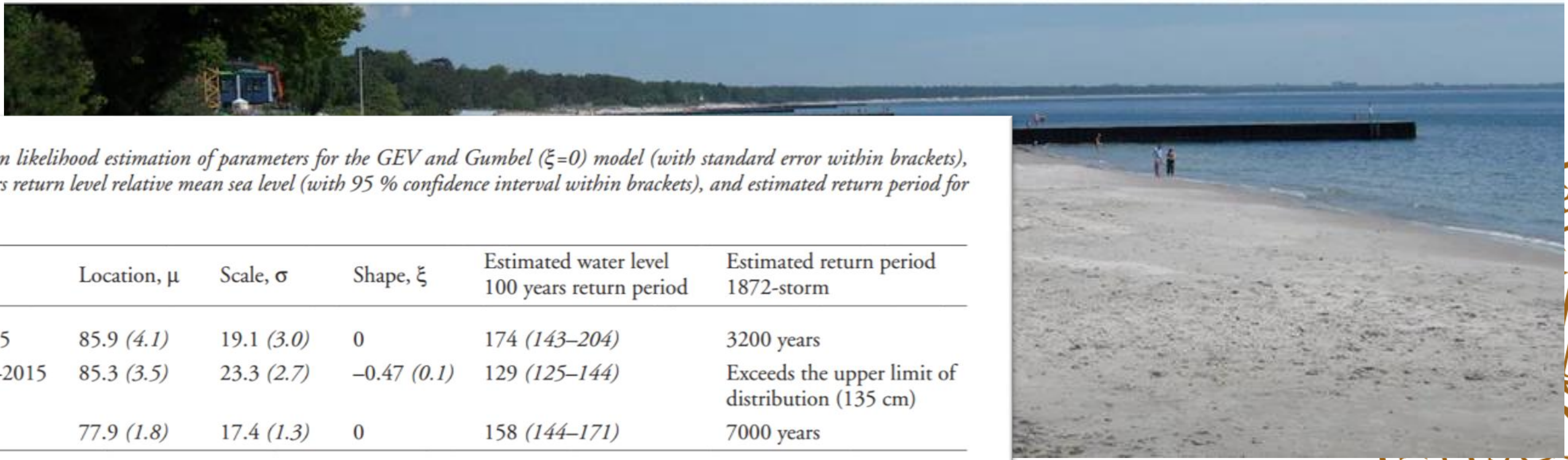


Table 4. *Maximum likelihood estimation of parameters for the GEV and Gumbel (ξ=0) model (with standard error within brackets), estimated 100-years return level relative mean sea level (with 95 % confidence interval within brackets), and estimated return period for the 1872 storm.*

| | Location, μ | Scale, σ | Shape, ξ | Estimated water level 100 years return period | Estimated return period 1872-storm |
|---|---|---|---|---|---|
| Skanör 1992–2015 | 85.9 *(4.1)* | 19.1 *(3.0)* | 0 | 174 *(143–204)* | 3200 years |
| Klagshamn 1961–2015 | 85.3 *(3.5)* | 23.3 *(2.7)* | –0.47 *(0.1)* | 129 *(125–144)* | Exceeds the upper limit of distribution (135 cm) |
| Ystad 1886–1987 | 77.9 *(1.8)* | 17.4 *(1.3)* | 0 | 158 *(144–171)* | 7000 years |

Fredriksson, C et al. 2016, STATISTICAL ANALYSIS OF EXTREME SEA WATER LEVELS AT THE FALSTERBO PENINSULA, SOUTH SWEDEN. J. Water Management and research