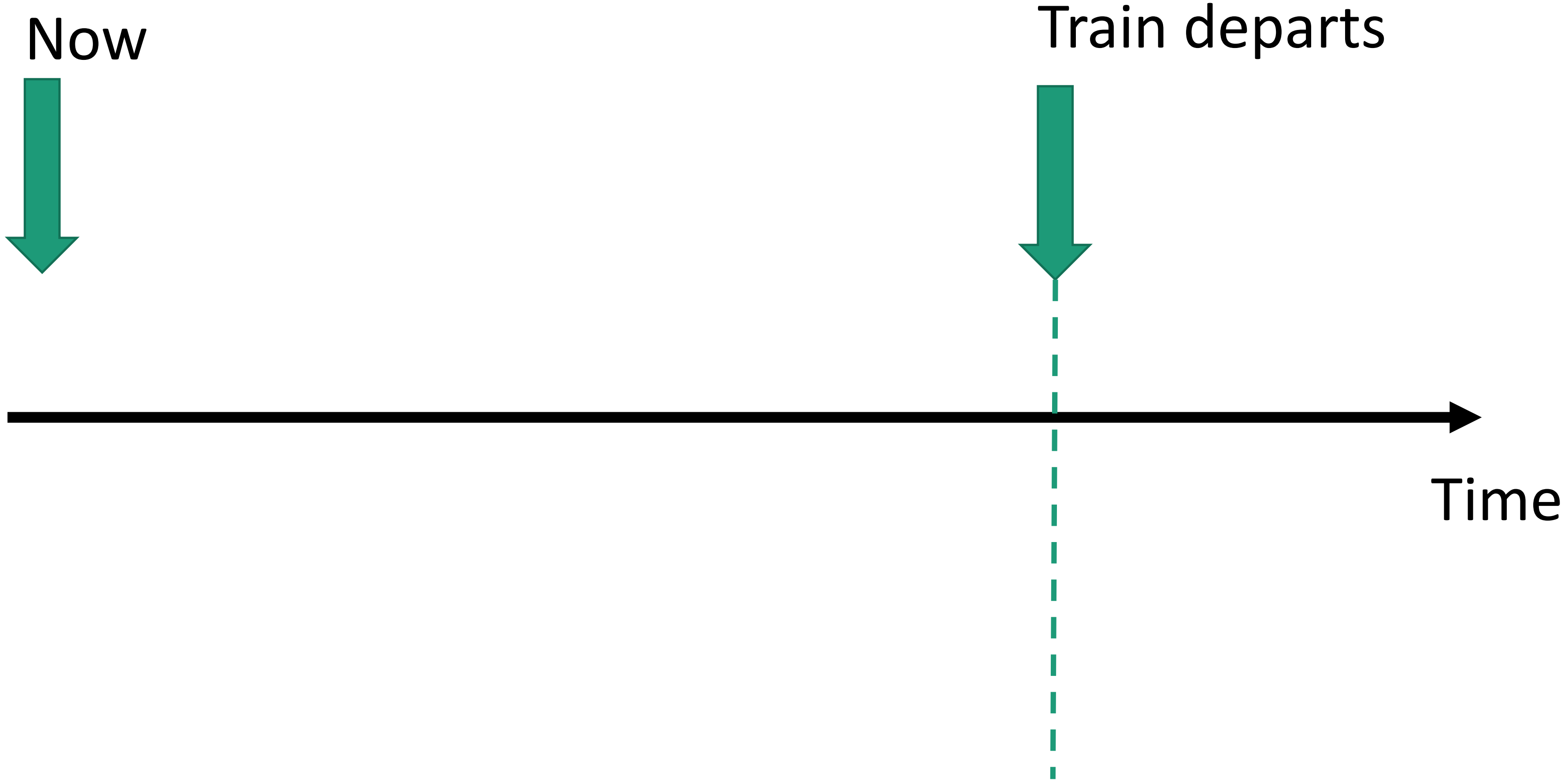
The importance of considering extreme and rare events in decision making

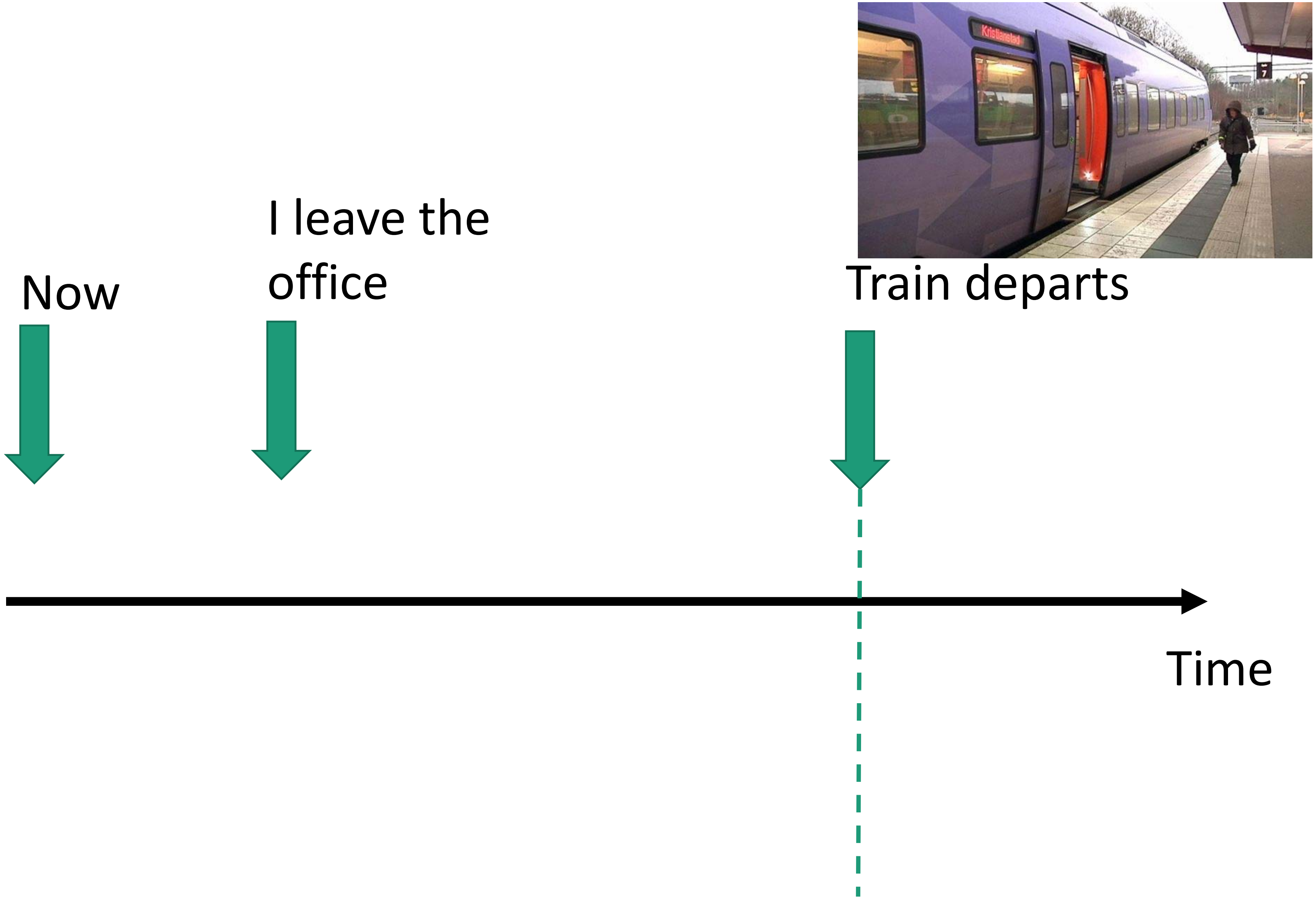
Ullrika Sahlin, Centre of Environmental and Climate Research

Lund University, Sweden

Ullrika.Sahlin@cec.lu.se

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


Now
Train departs
Time



LUND UNIVERSITY

I leave the office

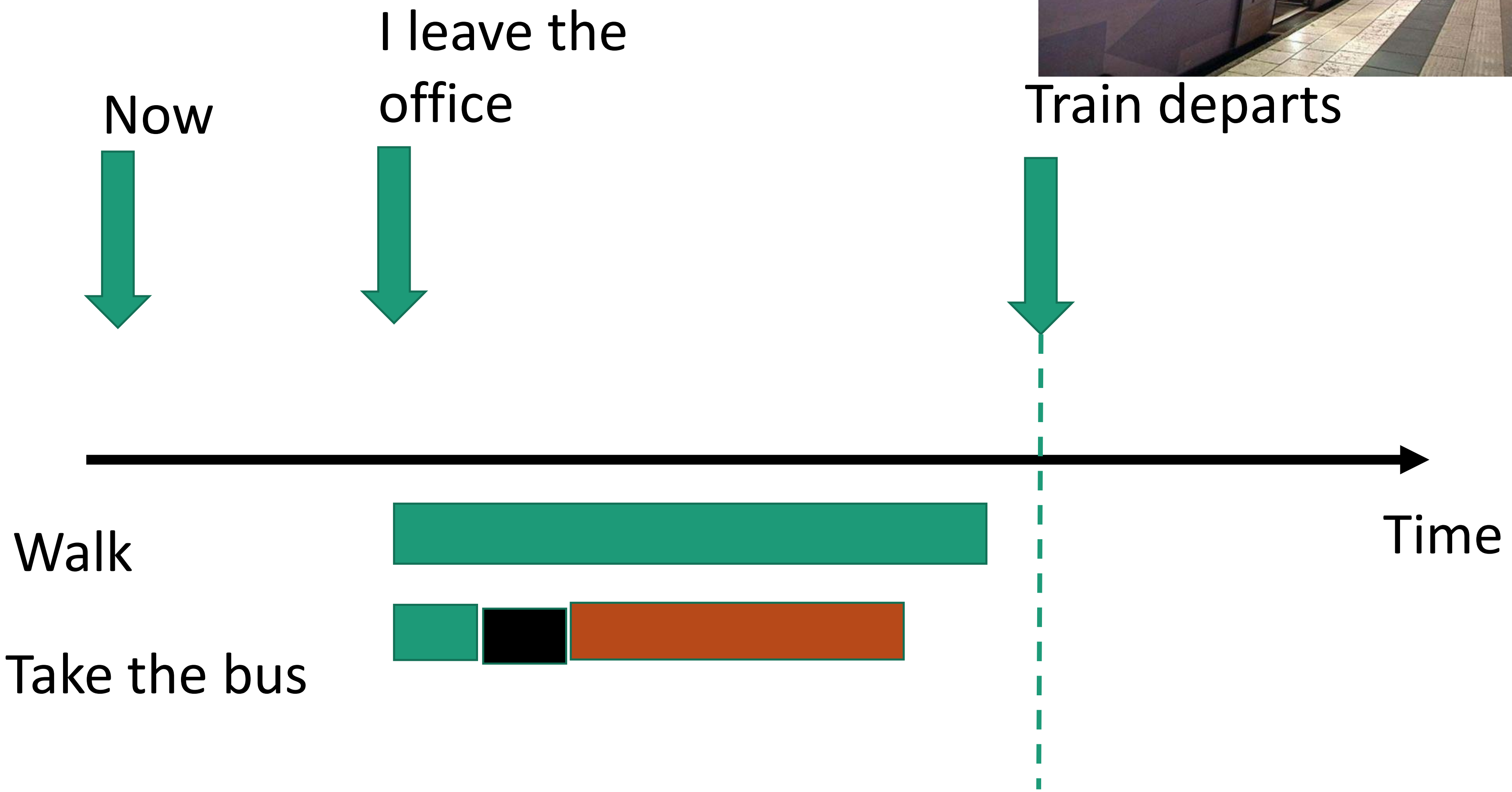
Now

Train departs

Walk

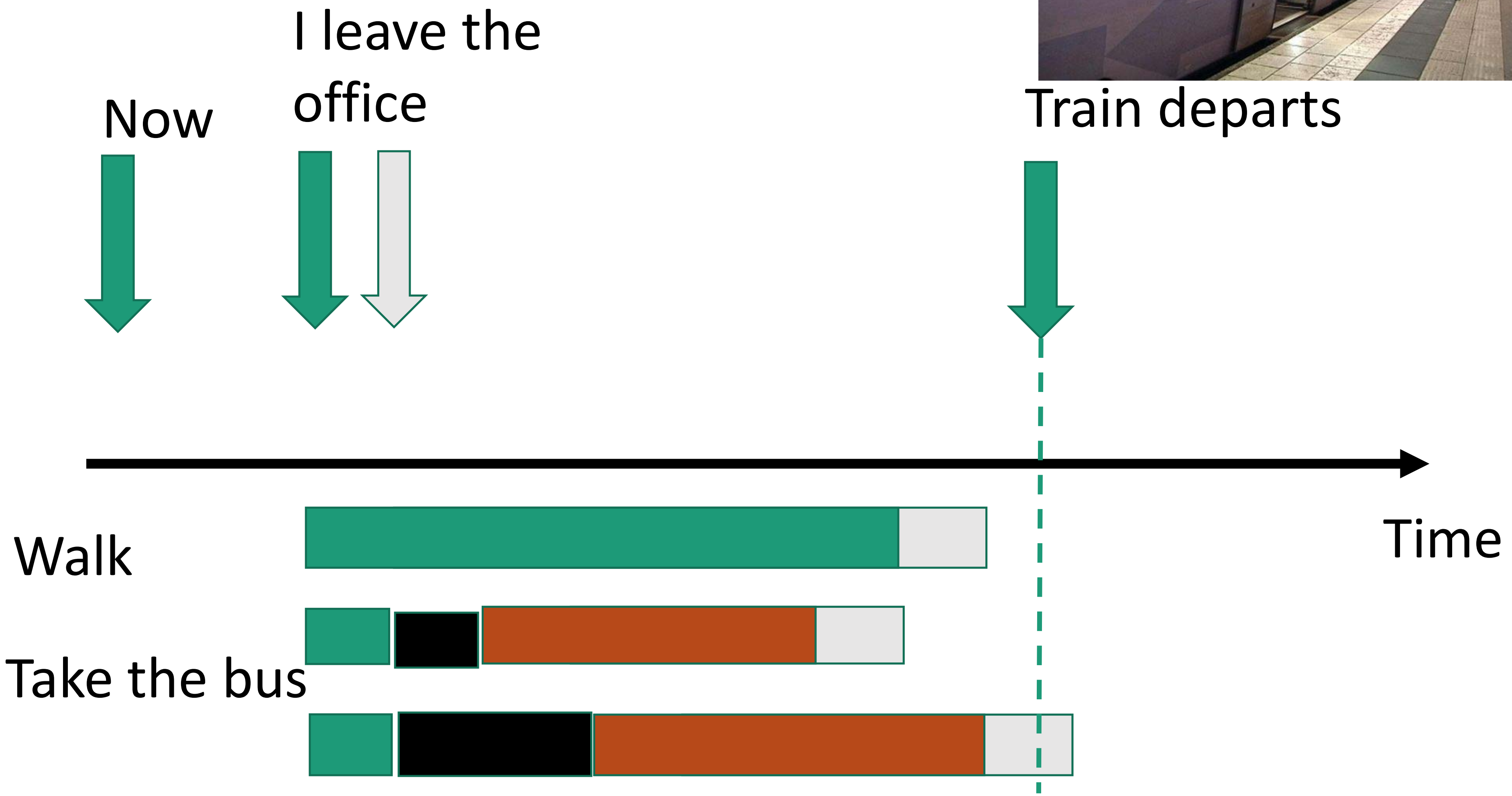
Time

LUND UNIVERSITY


Now
I leave the office
Train departs
Walk
Take the bus
Time

LUND UNIVERSITY

LUND UNIVERSITY

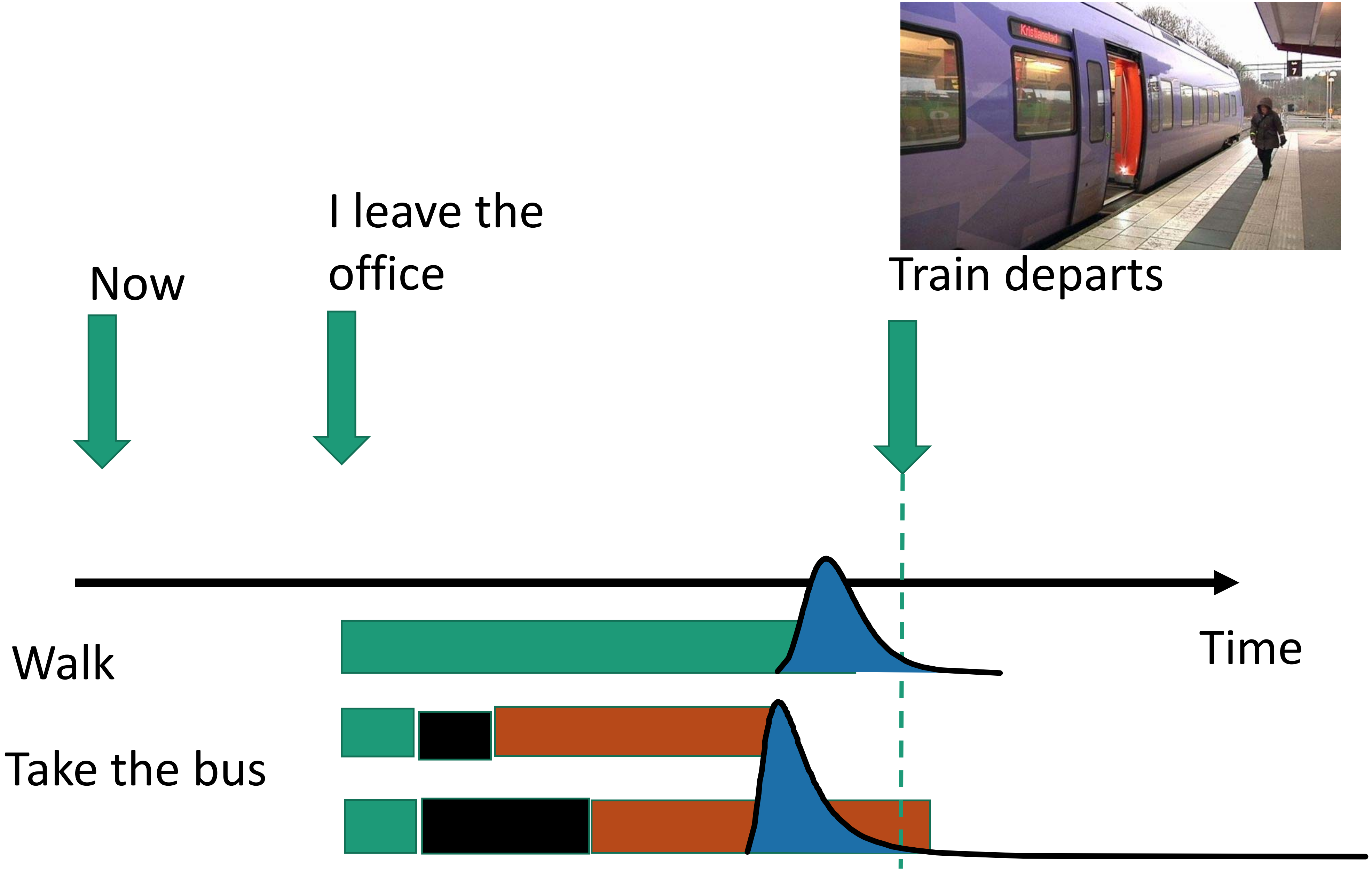


I leave the office
Now
Train departs
Walk
Time
Take the bus

Now
I leave the office
Train departs
Time
Walk
Take the bus

What makes a decision?

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



LUND UNIVERSITY

Outline

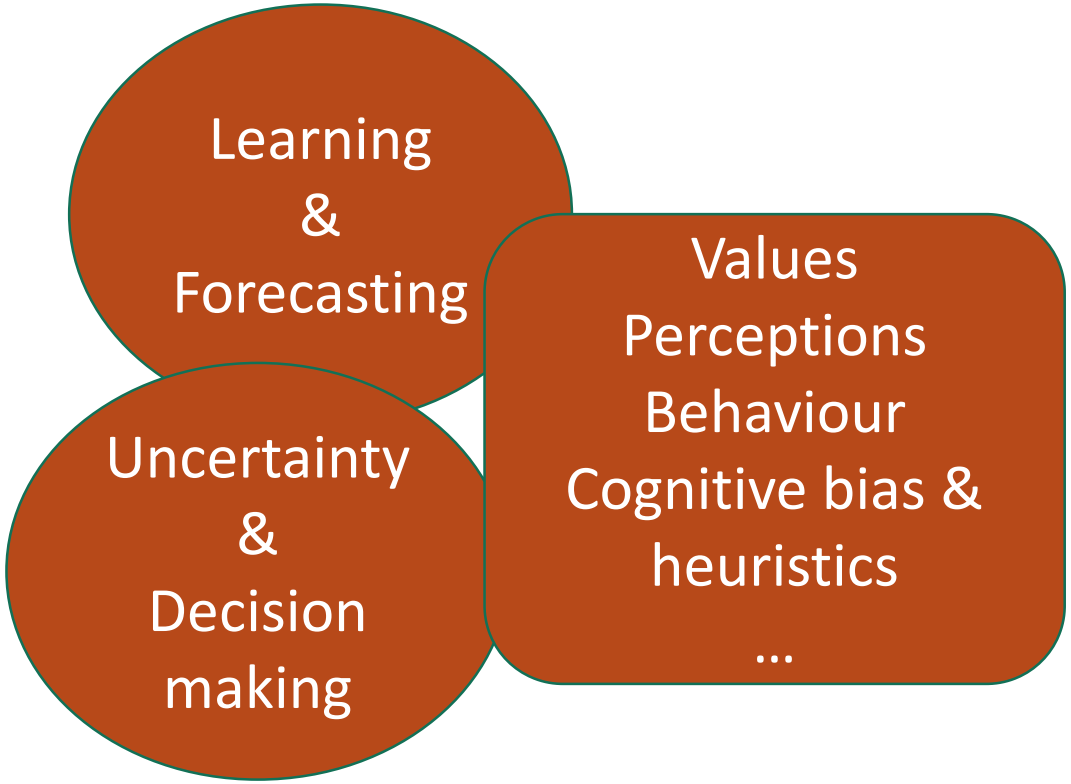
- Decisions are often far from simple
- Learning & forecasting to make decisions
- Extreme events and uncertainty
- Consider extreme events in system and knowledge dimensions
- More than one scientific perspective on extreme events

Coastline erosion and sea level rise

- It is desirable to live close to the sea, but coastline erosion cause
- 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

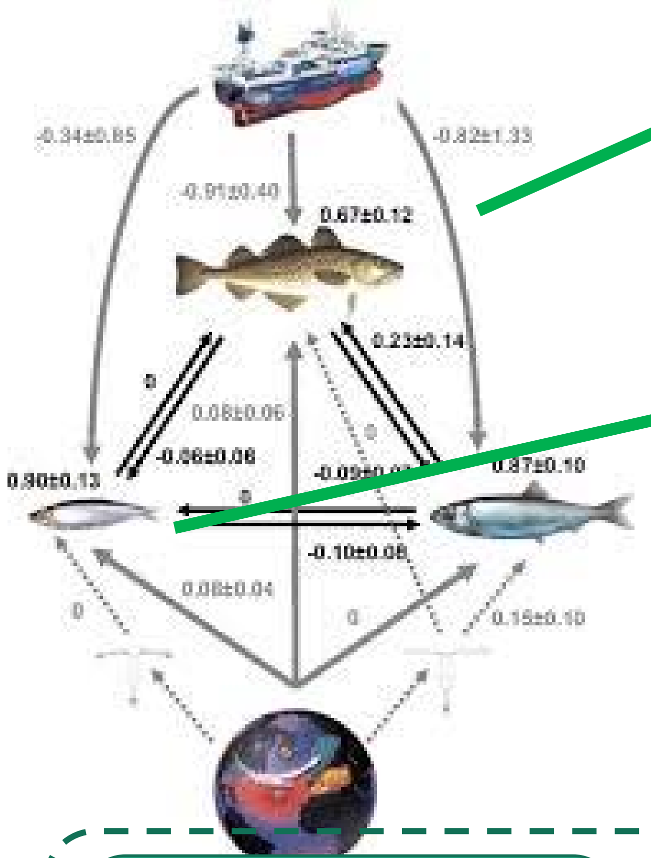

Learning
&
Forecasting
Uncertainty
&
Decision
making
Values
Perceptions
Behaviour
Cognitive bias &
heuristics
…

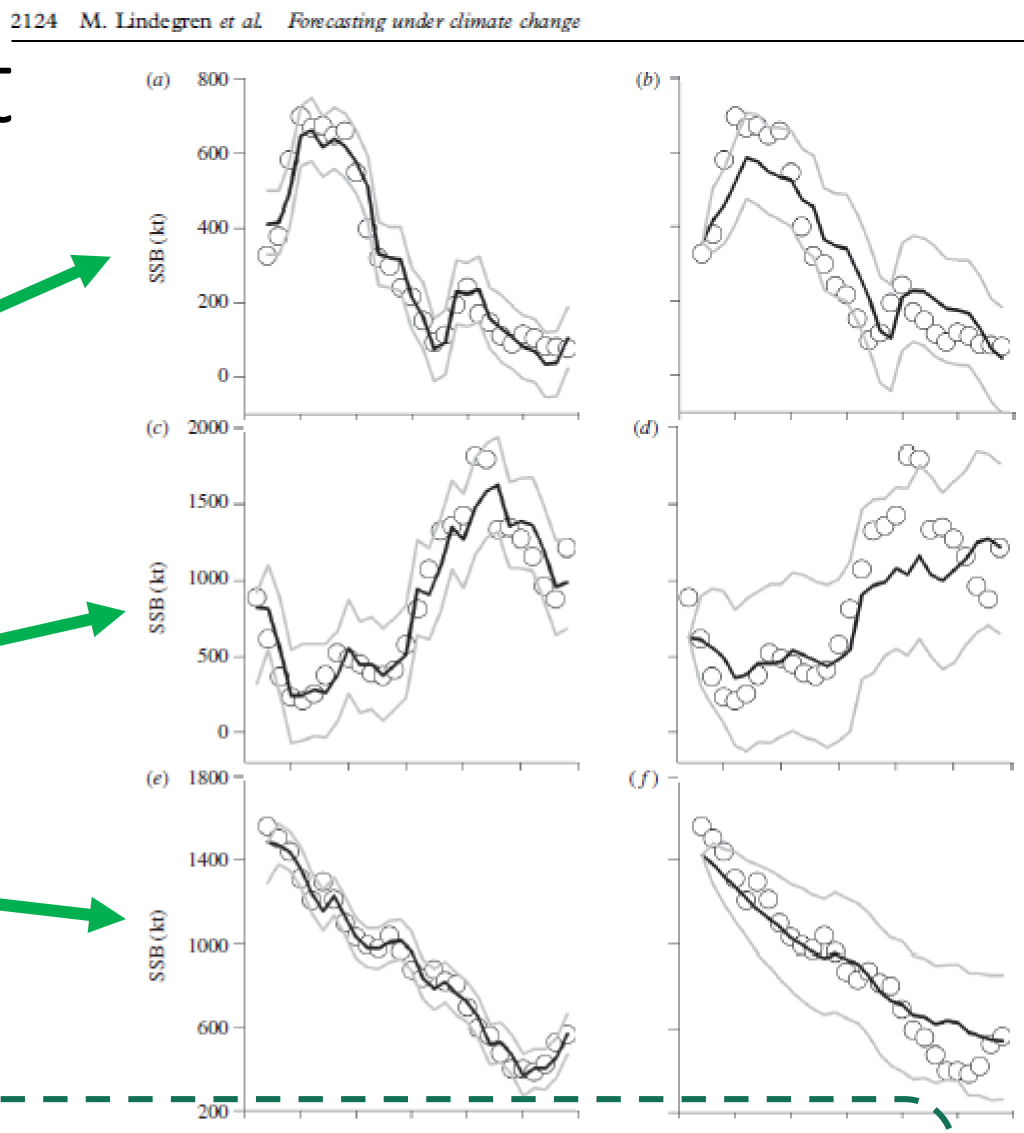
On the board

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

Fishery management

Learning



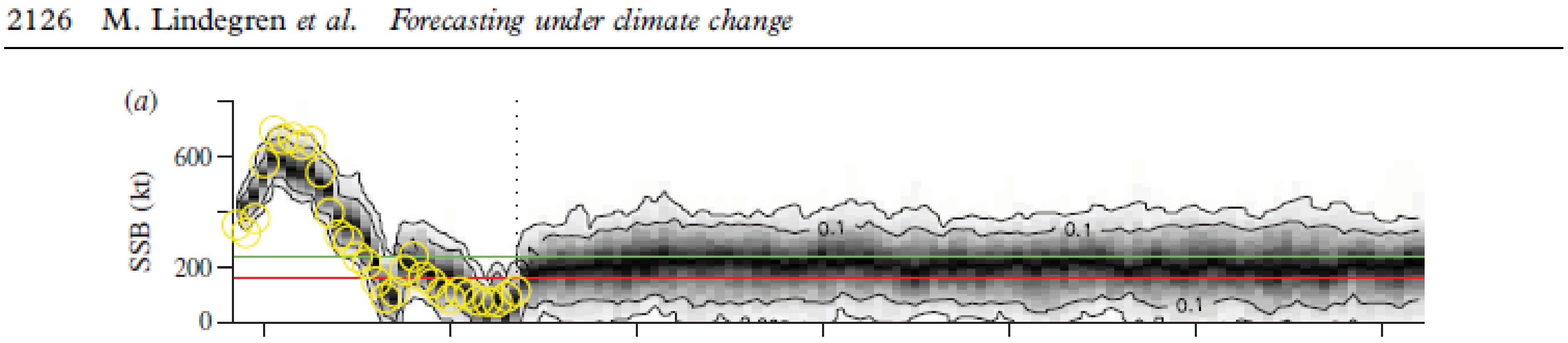


THEORY

EXPERT KNOWLEDGE

DATA

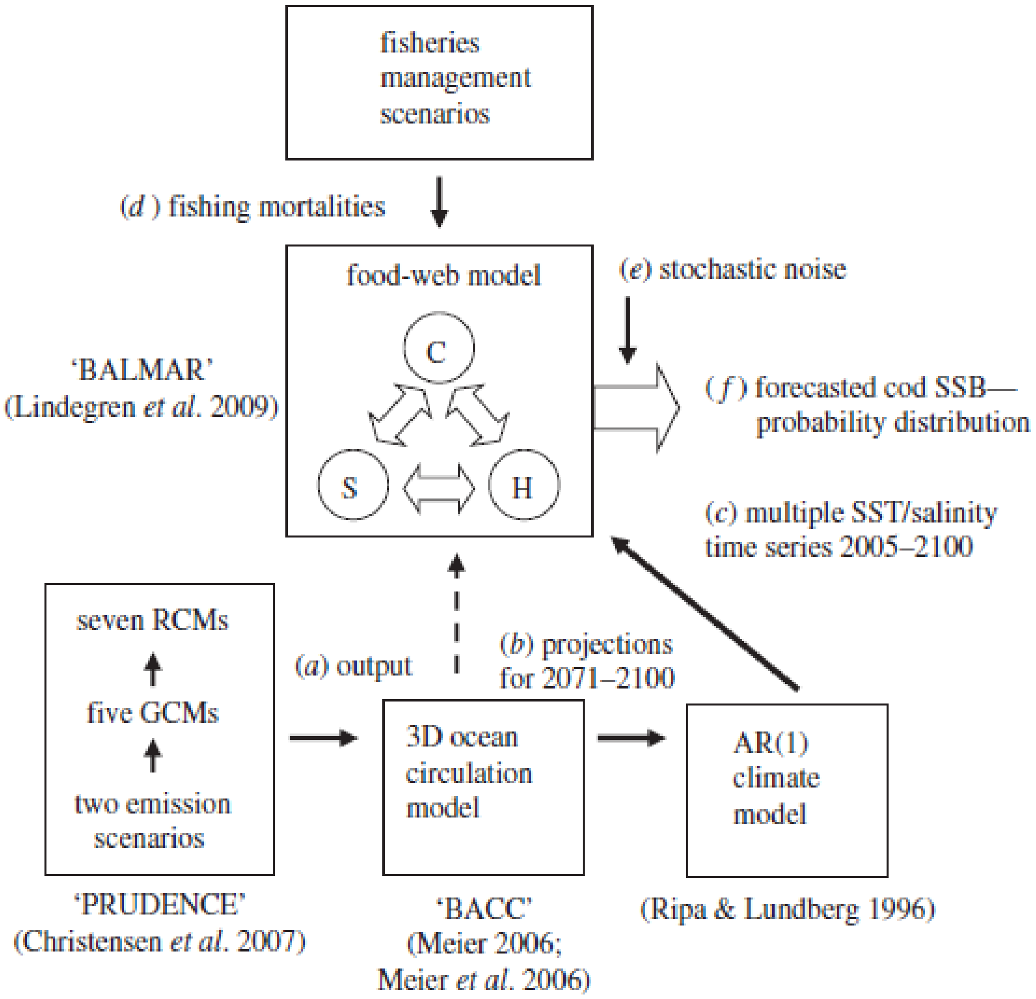
Fishery managment

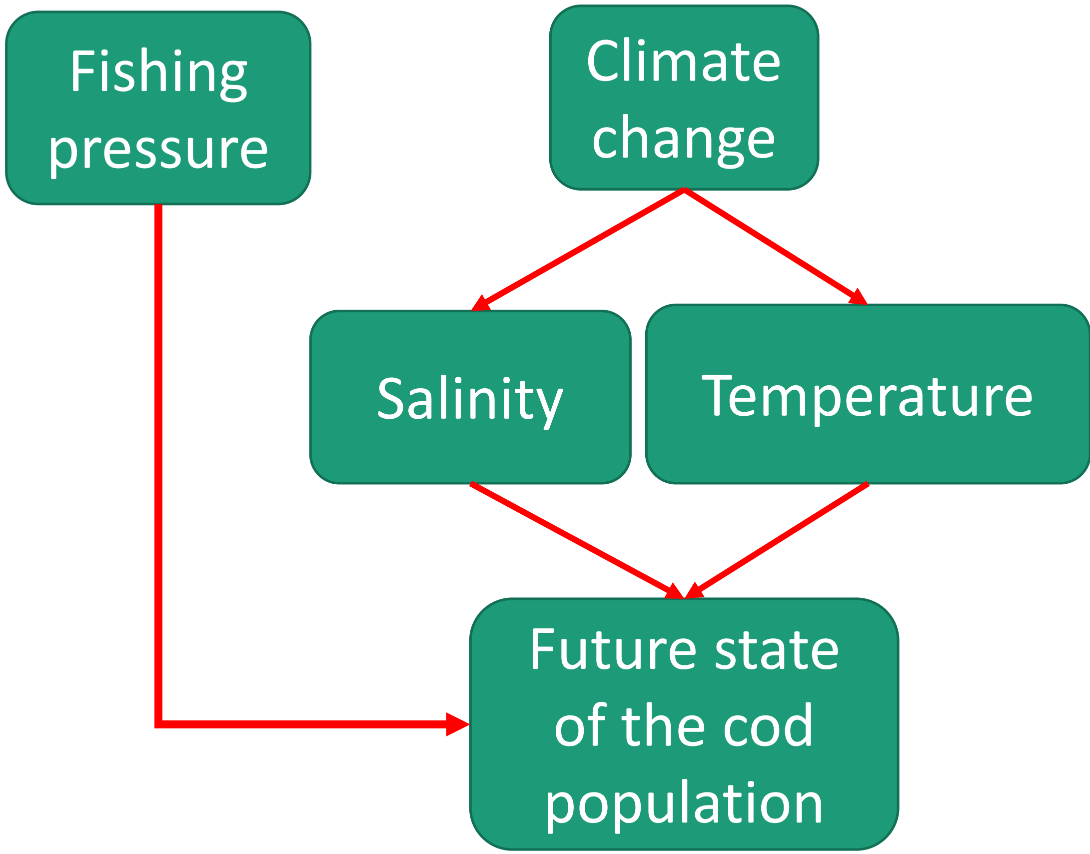


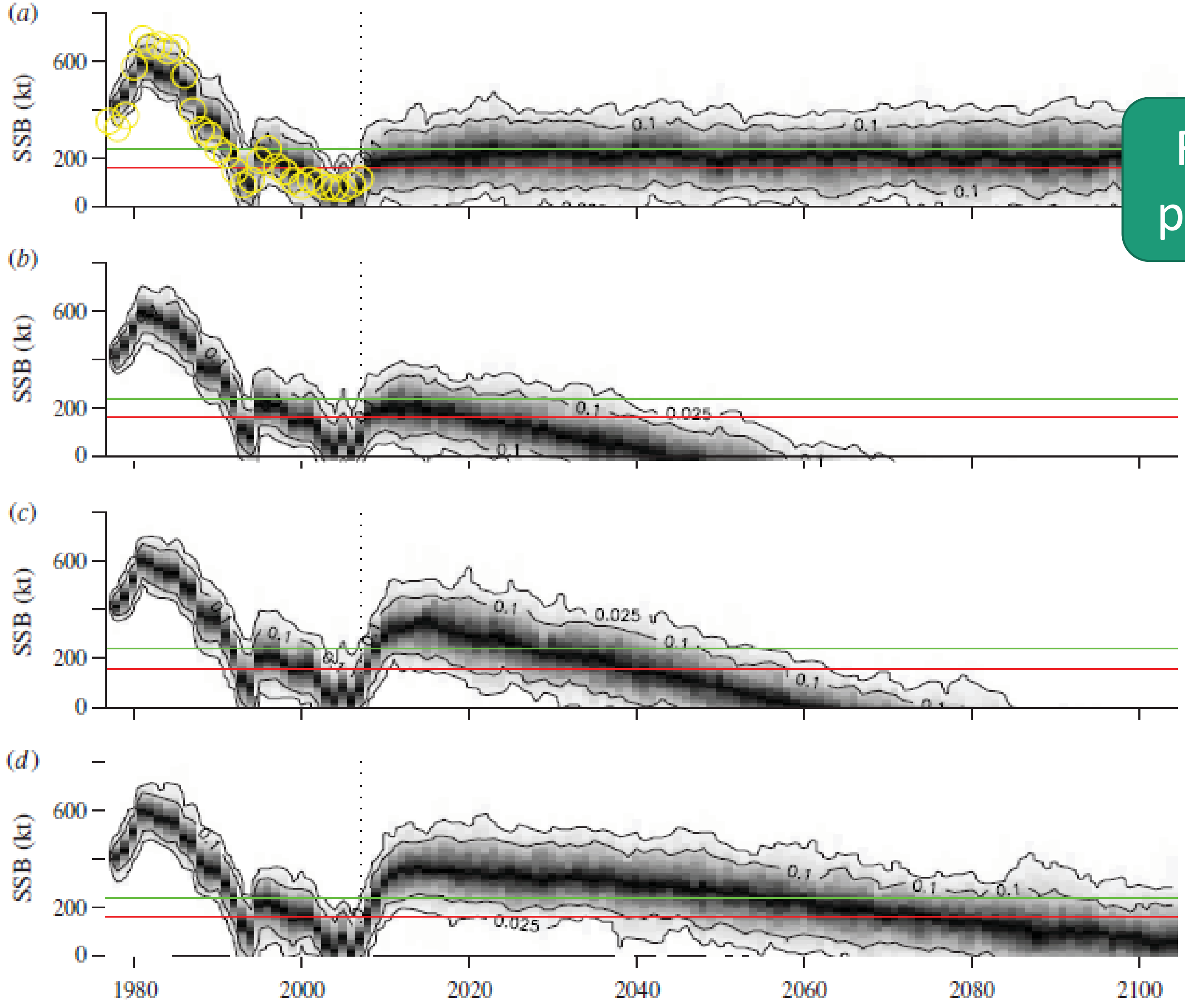
Learning

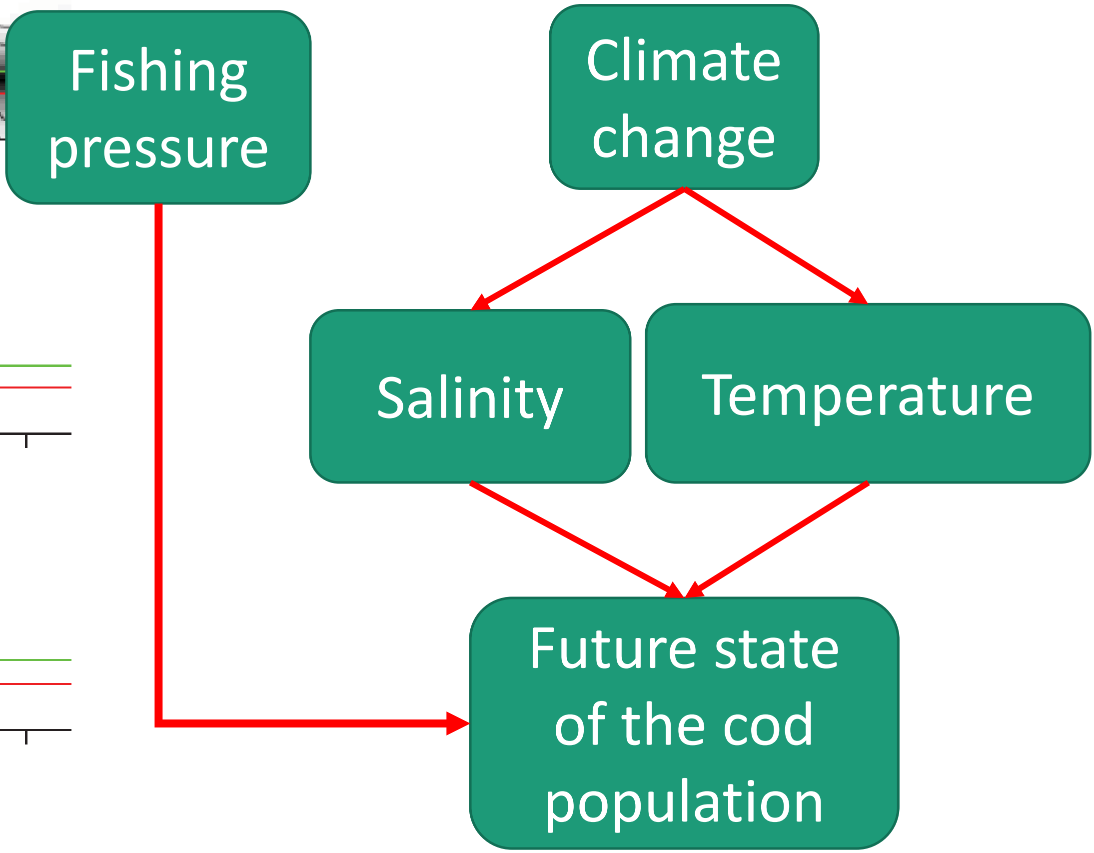
Forecasting

Forecasting under climate change

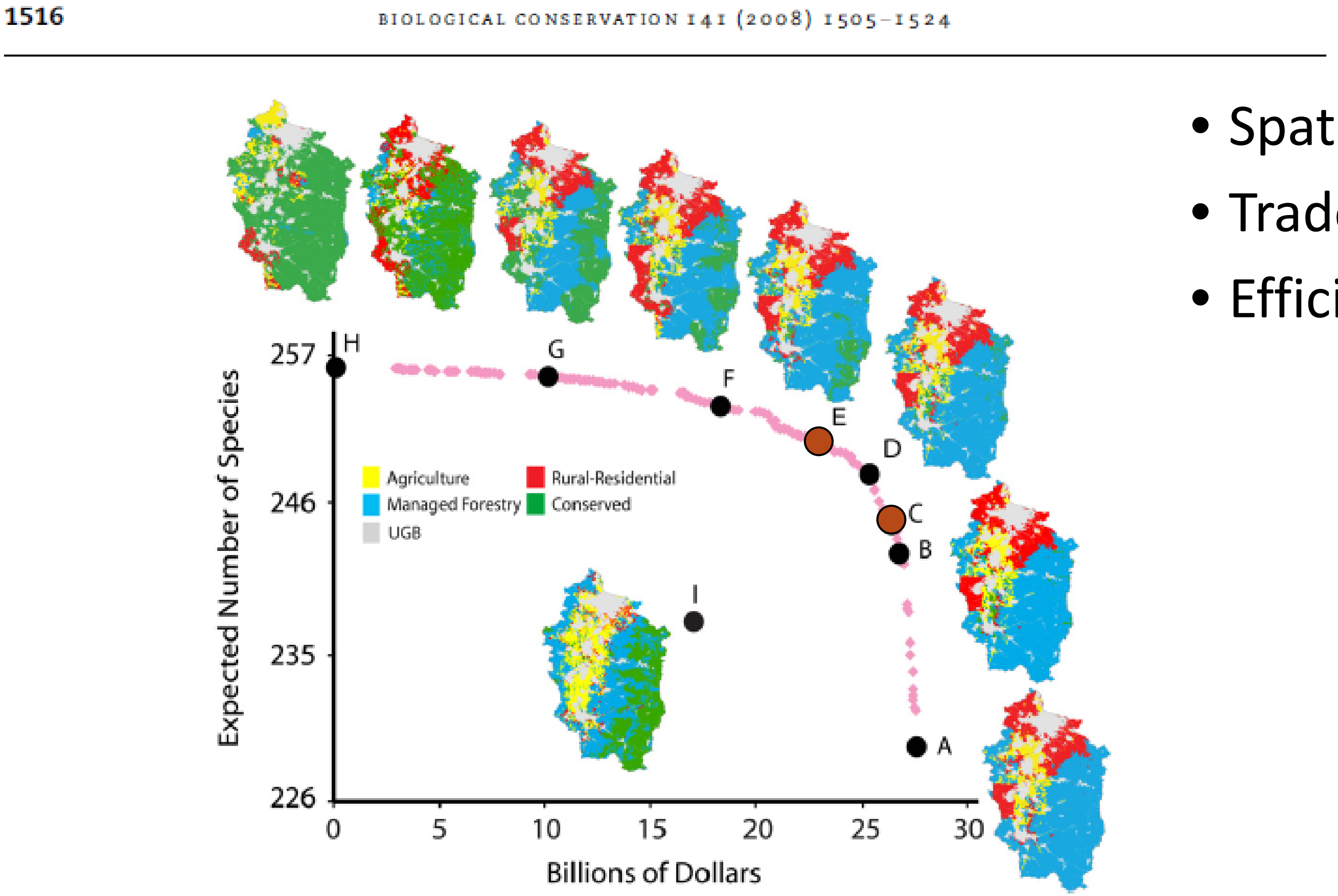





(a)
(b)
(c)
(d)
SSB (kt)
600
200
0
0.1
0.025
1980
2000
2020
2040
2060
2080
2100


Fishing pressure
Climate change
Salinity
Temperature
Future state of the cod population

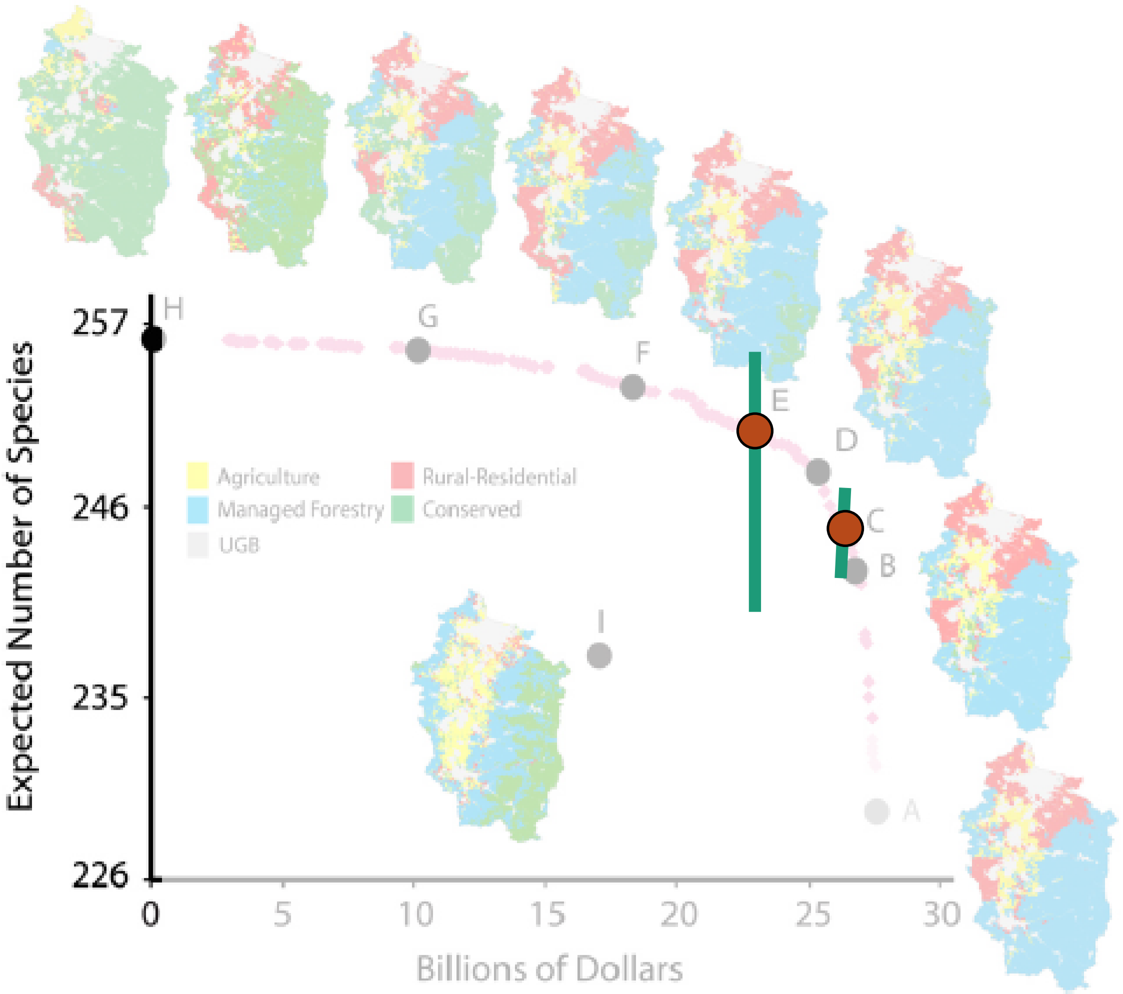
Biodiversity by land-use management



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

Biodiversity by land-use management

1516 BIOLOGICAL CONSERVATION 141 (2008) 1505–1524



- 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?

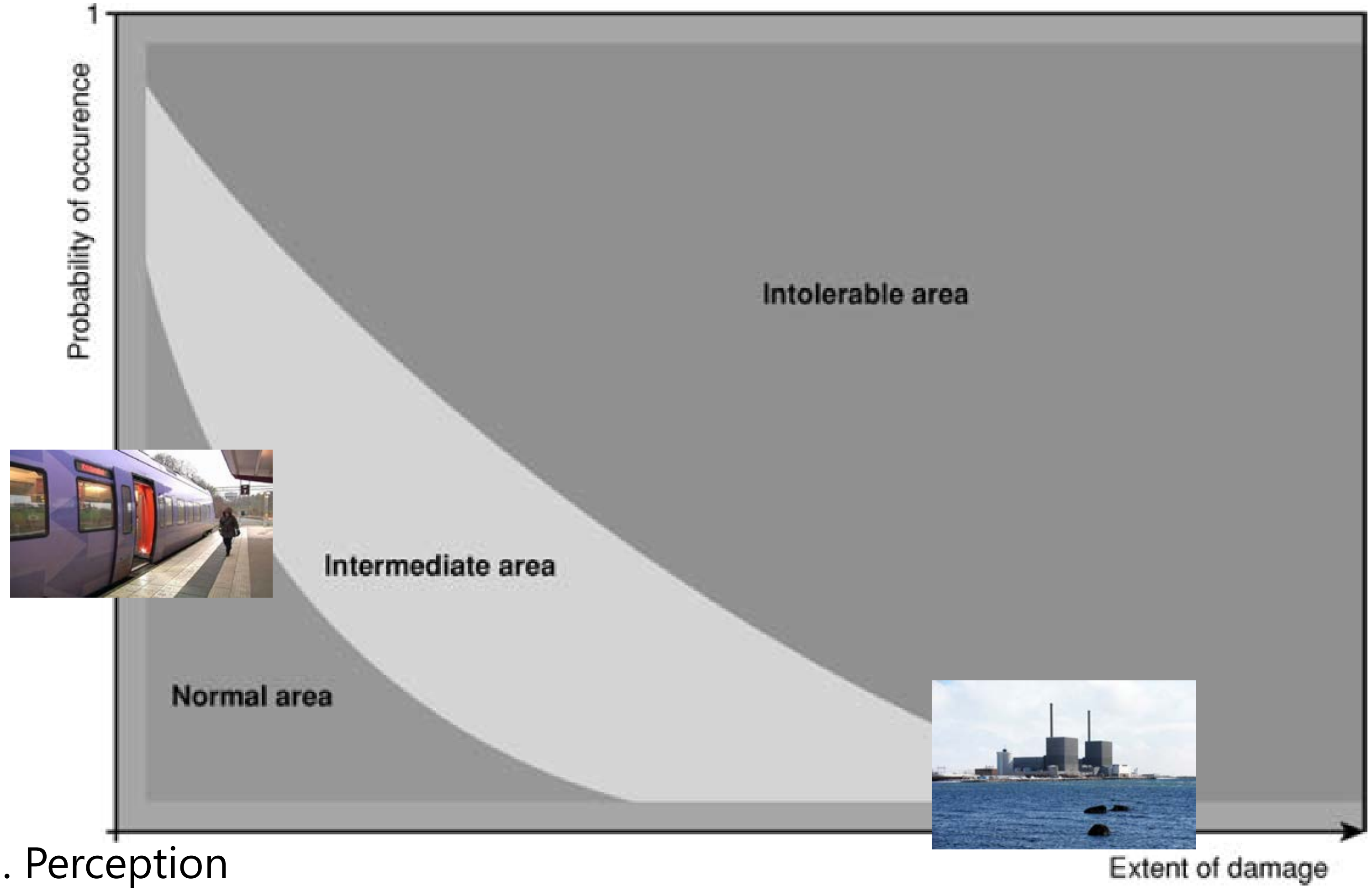
LUND UNIVERSITY

What is an extreme event?

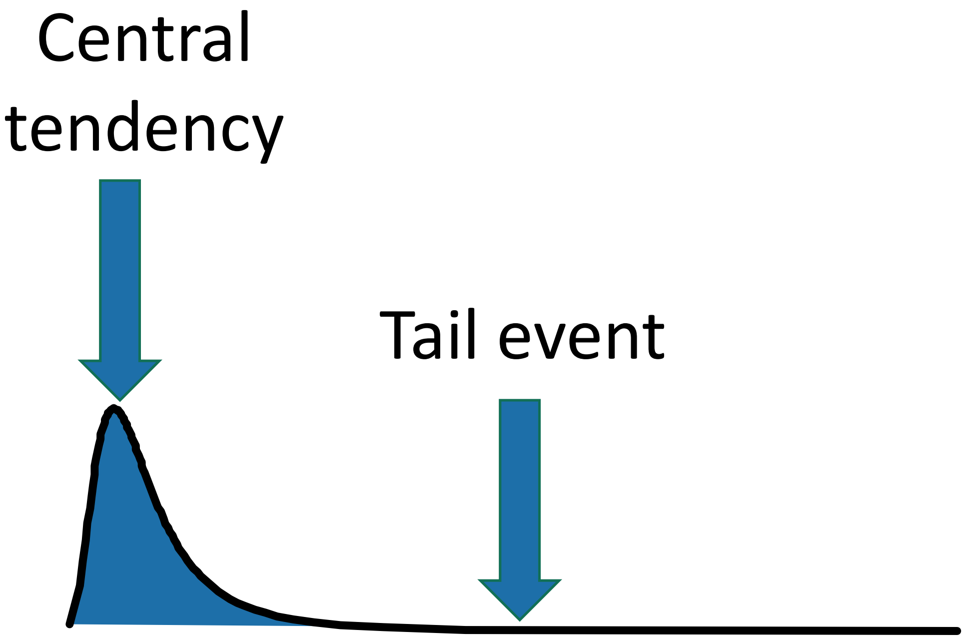
Kaplan and Garrick. 1981. On The Quantitative Definition of Risk. Risk Analysis

Klinke and Renn. 2002. Risk Analysis.

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

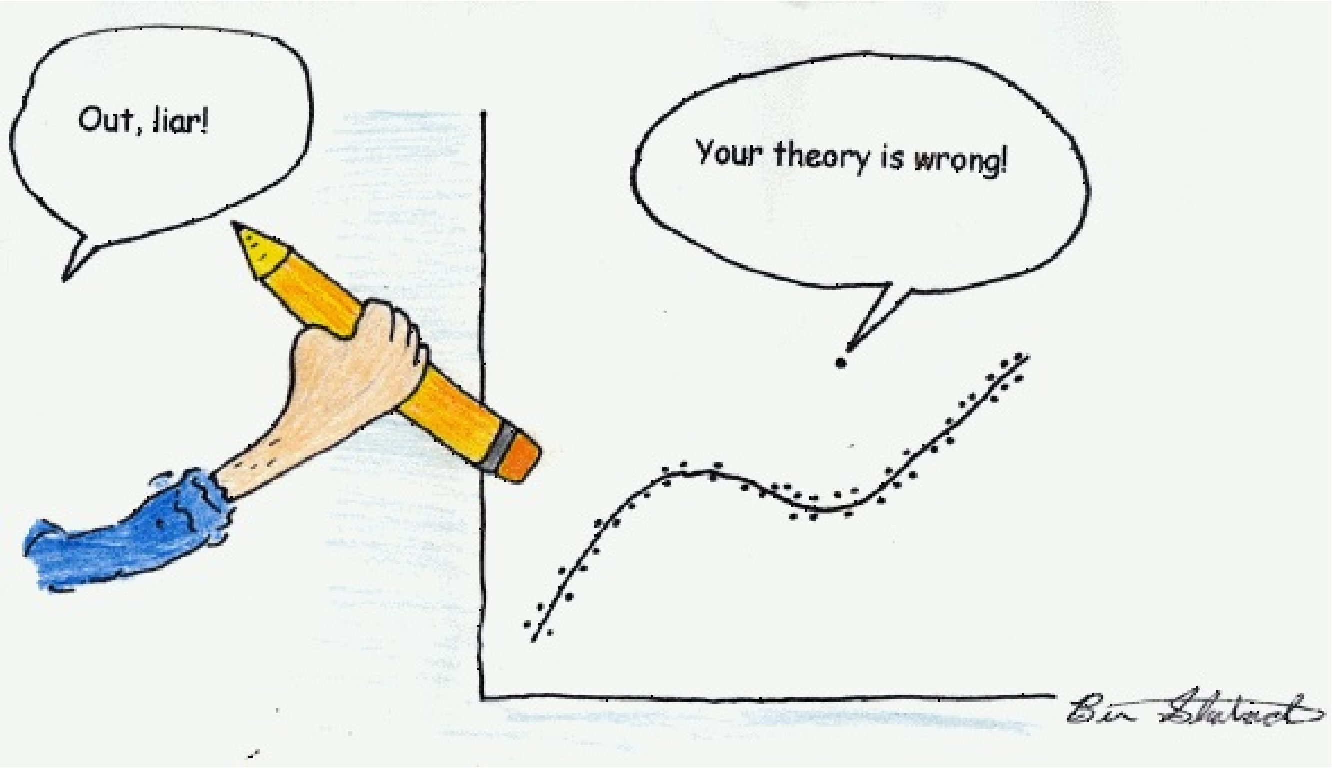


What is an extreme event?



What is an extreme event?

What is an extreme event?



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)

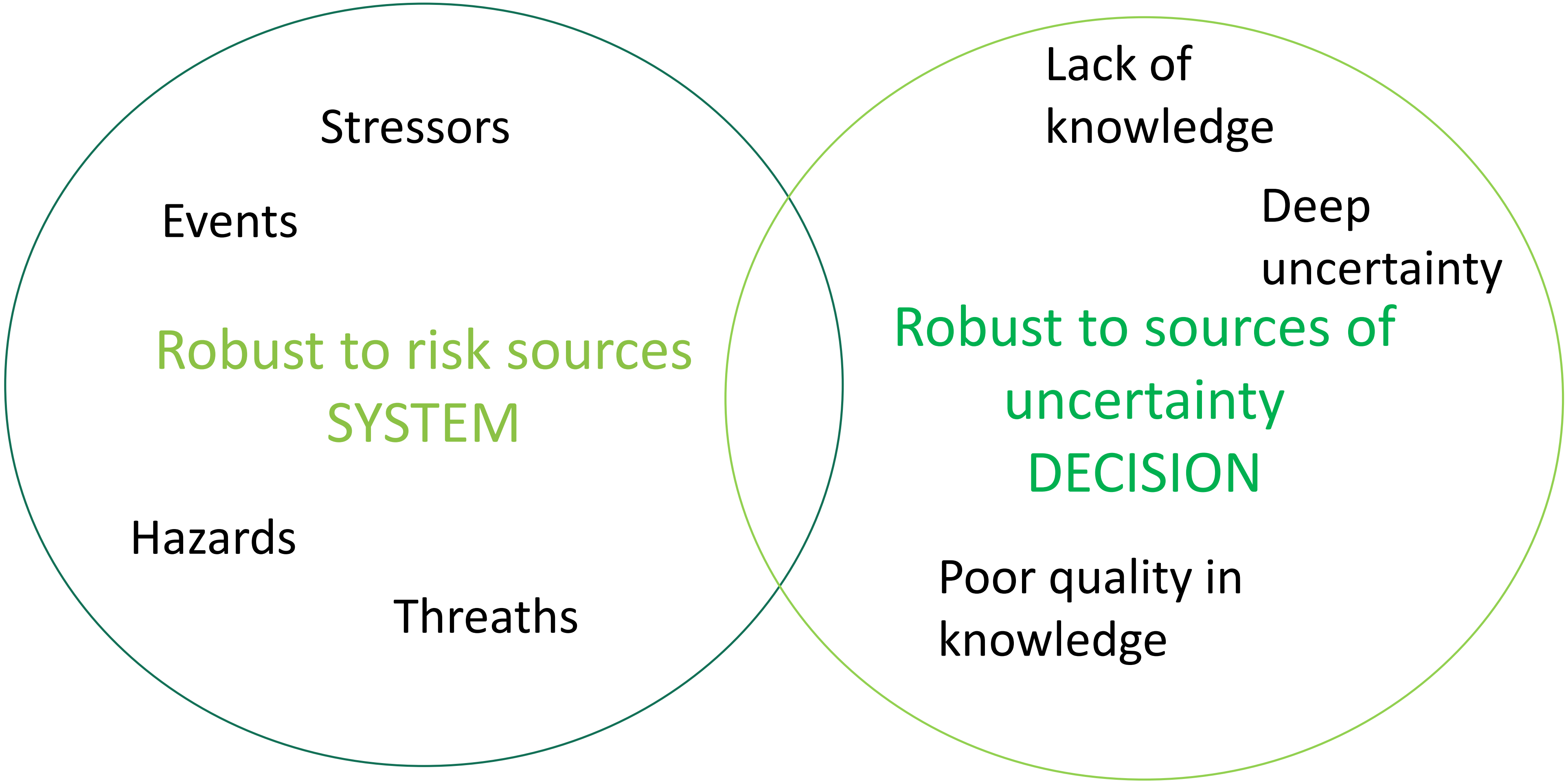
Strength in knowledge — S(K)

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 in Learning & Forecasting
is required to make robust decisions

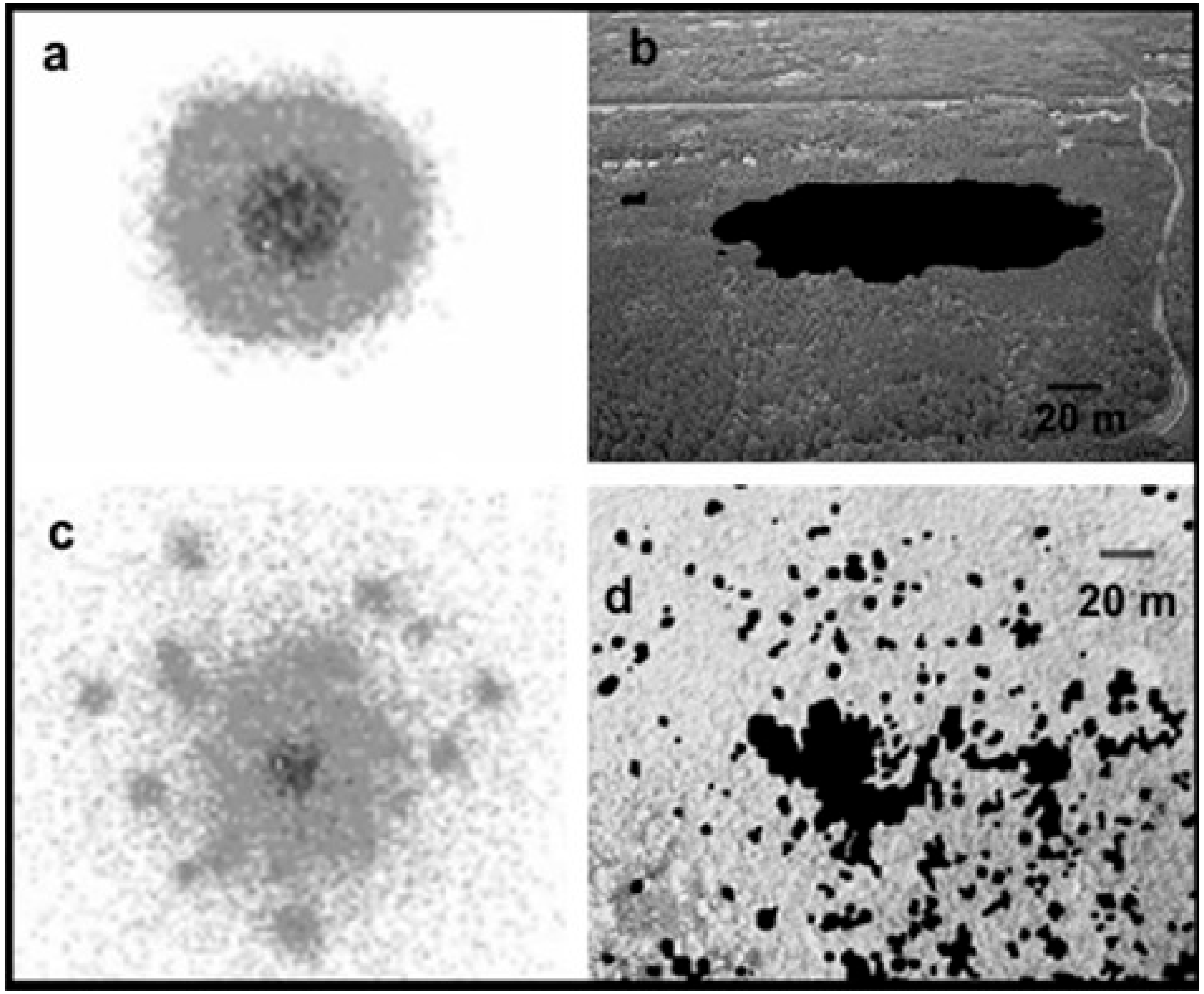
What is robust?



- “Robust to uncertainty” refers to a decision’s ability to be acceptable despite prevailing sources of uncertainty

Include extreme events in modelling

Short and long distance disperal



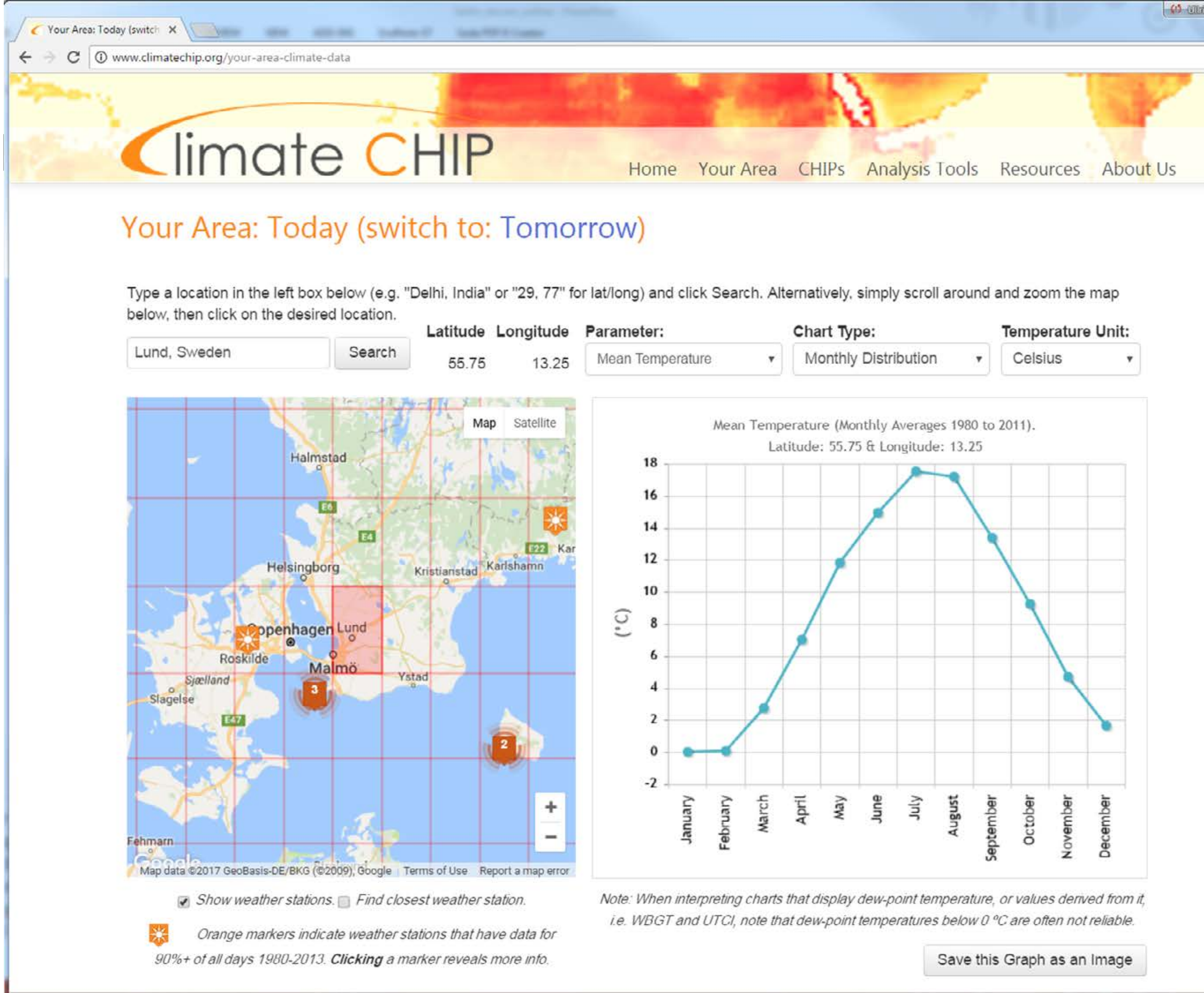
Marco, et al. 2011. Comparing short and long-distance dispersal: modelling and field case studies. Ecography

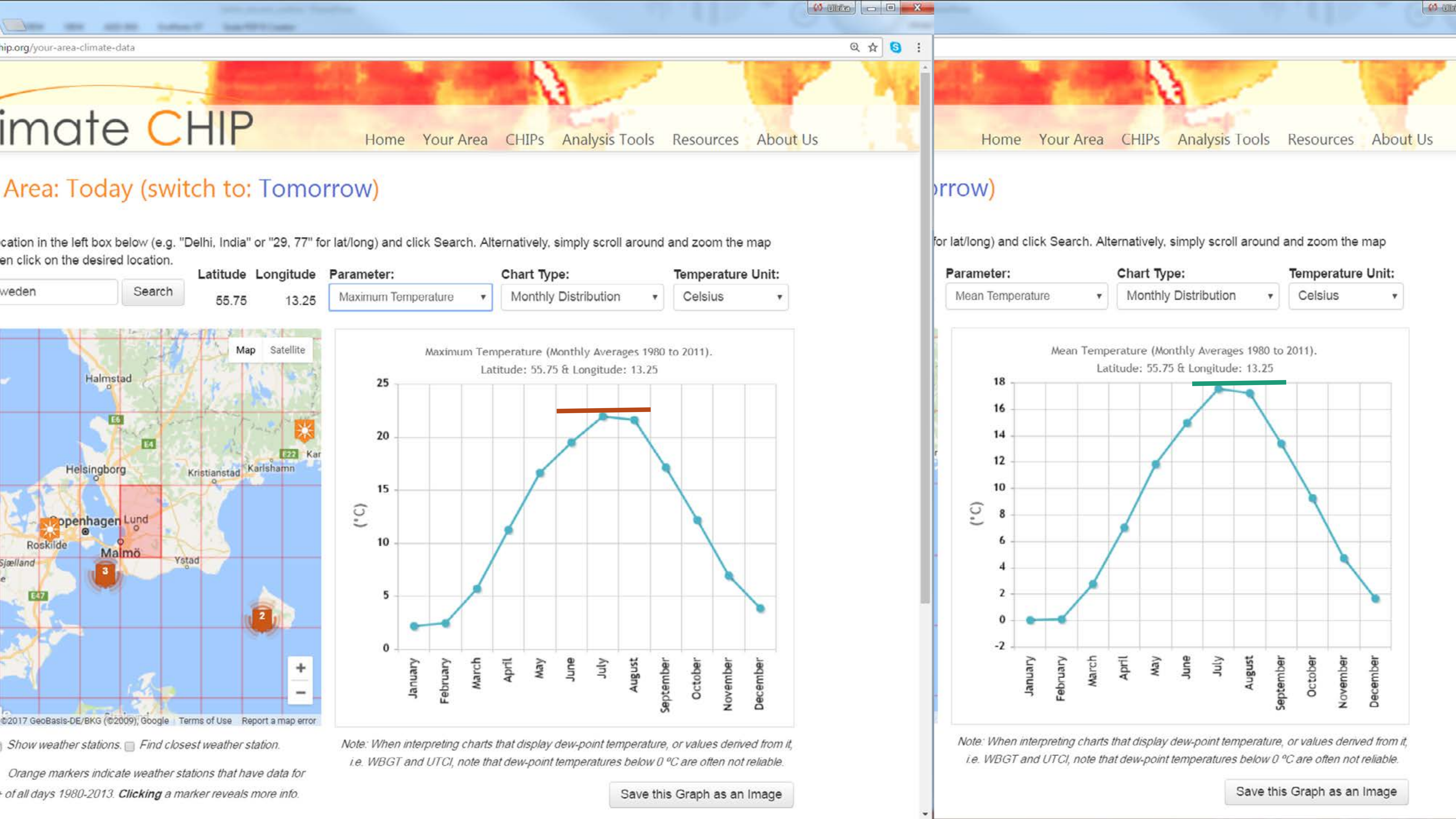
Include extreme events in modelling

Climate projections

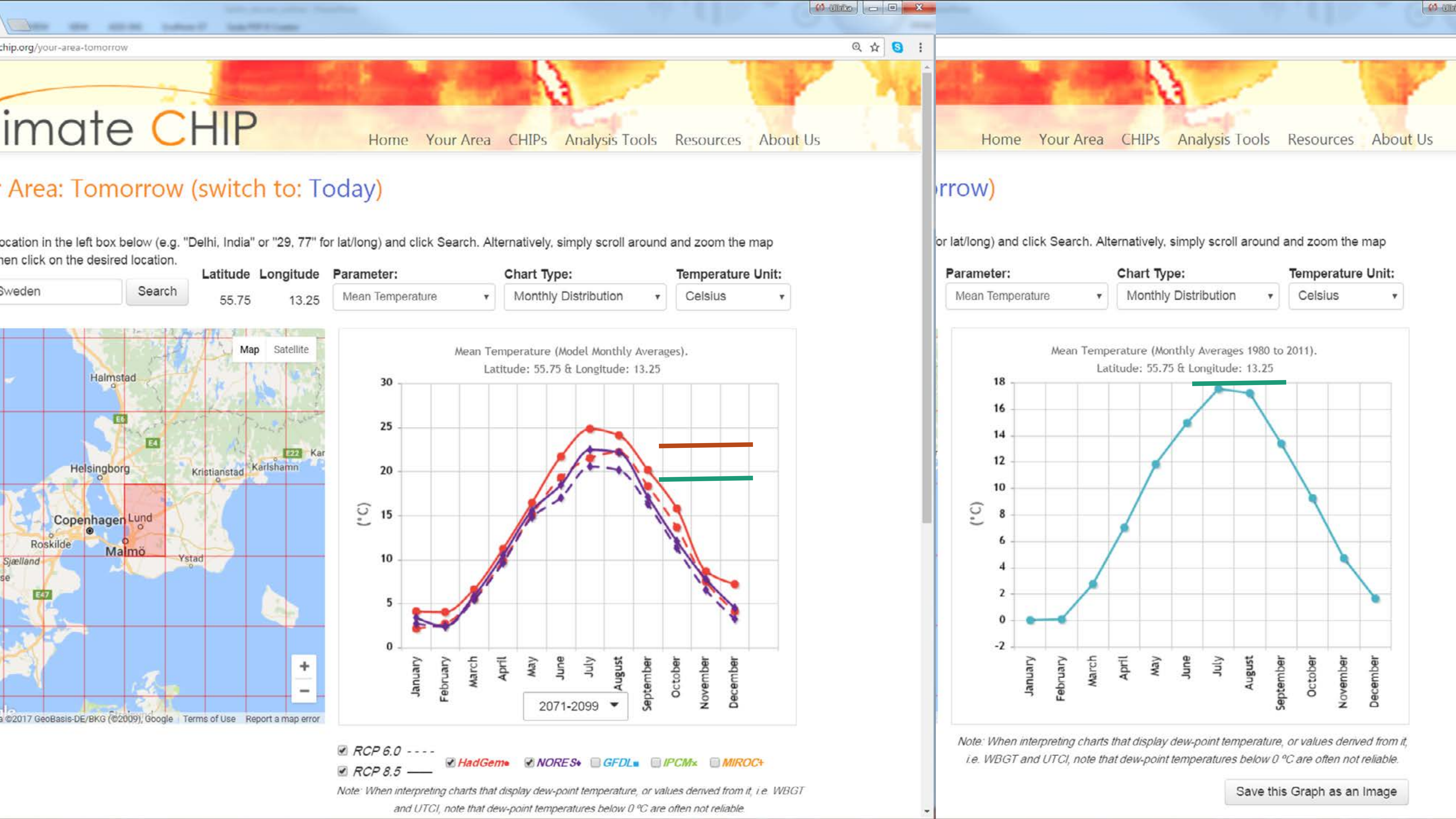
Include extre

Climate projections



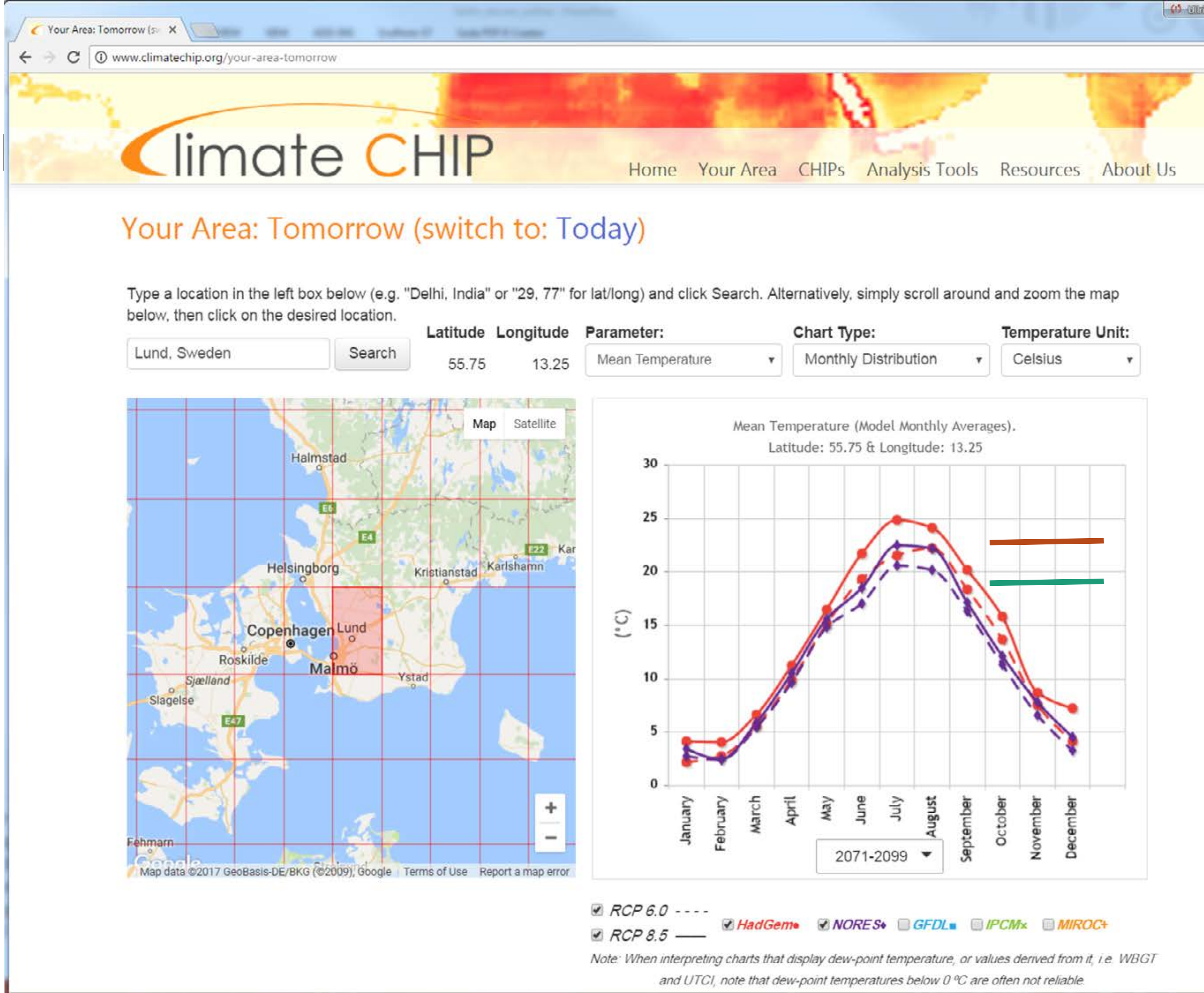


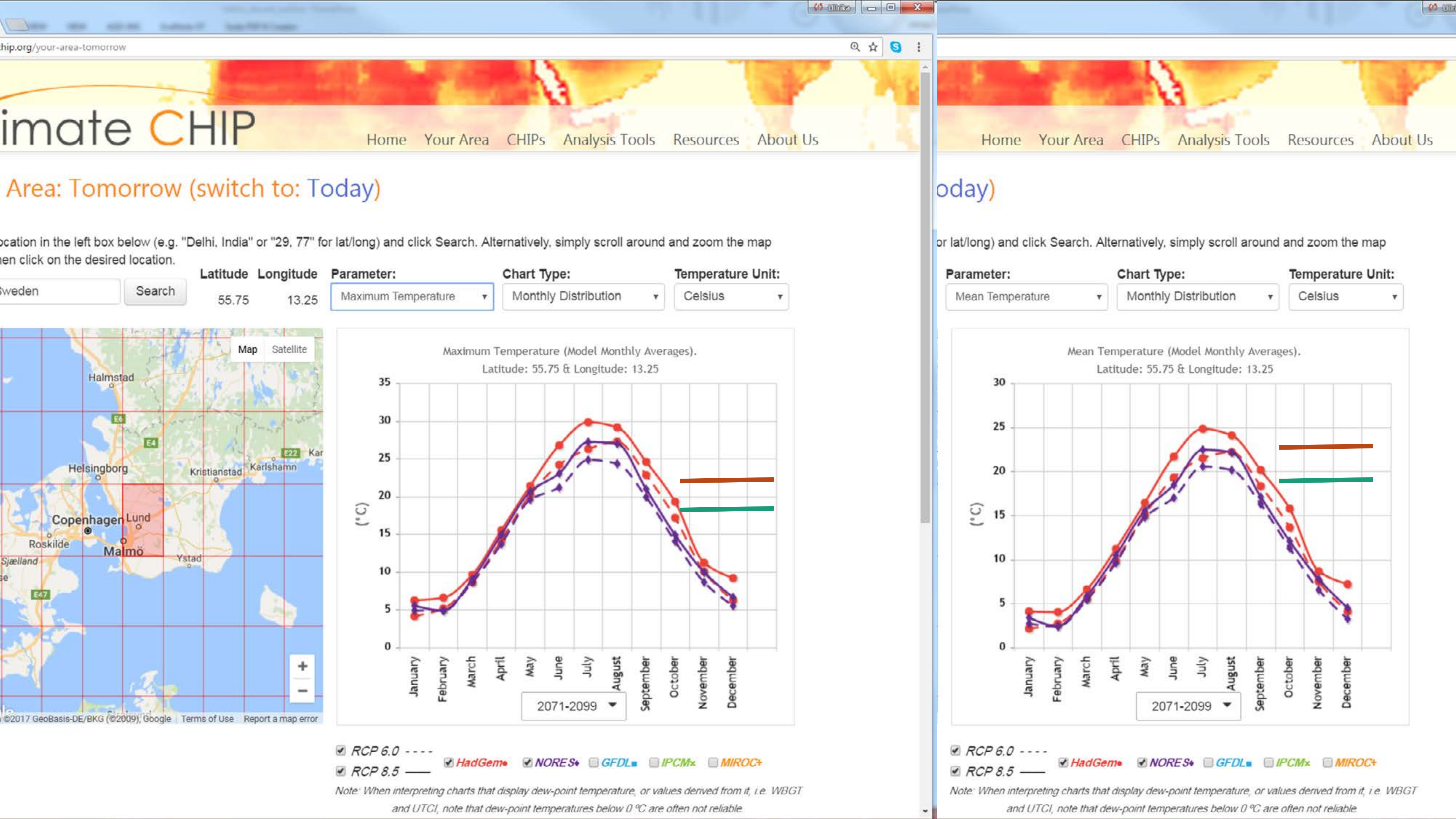
hip.org/your-area-climate-data
imate CHIP
Home
Your Area
CHIPs
Analysis Tools
Resources
About Us
Area: Today (switch to: Tomorrow)
cation in the left box below (e.g. "Delhi, India" or "29, 77" for lat/long) and click Search. Alternatively, simply scroll around and zoom the map
en click on the desired location.
weden
Search
Latitude
Longitude
55.75
13.25
Parameter:
Maximum Temperature
Chart Type:
Monthly Distribution
Temperature Unit:
Celsius
Map
Satellite
Halmstad
Helsingborg
Kristianstad
Karlshamn
Copenhagen
Lund
Roskilde
Malmö
Ystad
Sjælland
©2017 GeoBasis-DE/BKG (©2009), Google
Terms of Use
Report a map error
Maximum Temperature (Monthly Averages 1980 to 2011).
Latitude: 55.75 & Longitude: 13.25
(°C)
25
20
15
10
5
0
January
February
March
April
May
June
July
August
September
October
November
December
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.
Save this Graph as an Image
Home
Your Area
CHIPs
Analysis Tools
Resources
About Us
rrow)
for lat/long) and click Search. Alternatively, simply scroll around and zoom the map
Parameter:
Mean Temperature
Chart Type:
Monthly Distribution
Temperature Unit:
Celsius
Mean Temperature (Monthly Averages 1980 to 2011).
Latitude: 55.75 & Longitude: 13.25
(°C)
18
16
14
12
10
8
6
4
2
0
-2
January
February
March
April
May
June
July
August
September
October
November
December
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.
Save this Graph as an Image


chip.org/your-area-tomorrow
imate CHIP
Home Your Area CHIPs Analysis Tools Resources About Us
Area: Tomorrow (switch to: Today)
ocation in the left box below (e.g. "Delhi, India" or "29, 77" for lat/long) and click Search. Alternatively, simply scroll around and zoom the map
hen click on the desired location.
Sweden
Search
Latitude Longitude
55.75 13.25
Parameter:
Mean Temperature
Chart Type:
Monthly Distribution
Temperature Unit:
Celsius
Map Satellite
Halmstad
Helsingborg
Kristianstad
Karlshamn
Copenhagen
Lund
Roskilde
Malmö
Ystad
Sjælland
©2017 GeoBasis-DE/BKG (©2009), Google Terms of Use Report a map error
Mean Temperature (Model Monthly Averages).
Latitude: 55.75 & Longitude: 13.25
(°C)
January February March April May June July August September October November December
2071-2099
RCP 6.0 - - - -
RCP 8.5 ——
HadGem NORES GFDL IPCM MIROC
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.
rrow)
or lat/long) and click Search. Alternatively, simply scroll around and zoom the map
Parameter:
Mean Temperature
Chart Type:
Monthly Distribution
Temperature Unit:
Celsius
Mean Temperature (Monthly Averages 1980 to 2011).
Latitude: 55.75 & Longitude: 13.25
(°C)
January February March April May June July August September October November December
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.
Save this Graph as an Image

Include extre

Climate projections

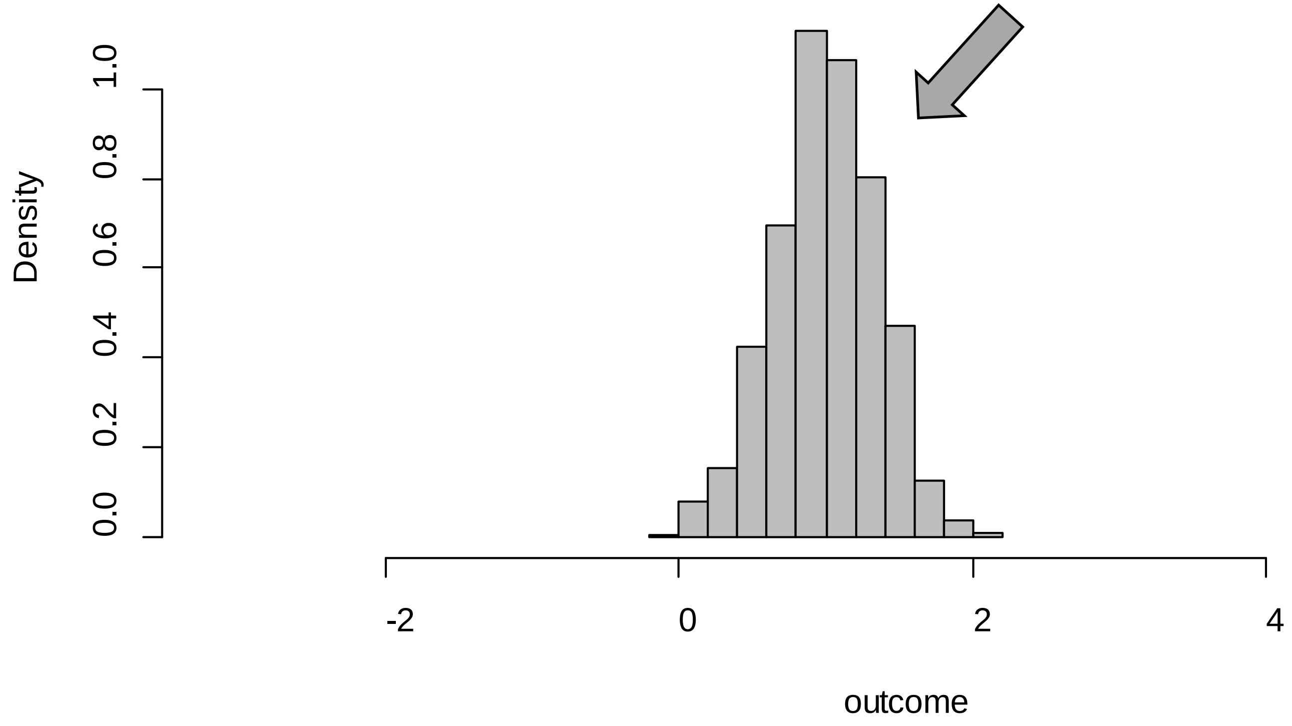



hip.org/your-area-tomorrow
imate CHIP
Home
Your Area
CHIPs
Analysis Tools
Resources
About Us
Area: Tomorrow (switch to: Today)
ocation in the left box below (e.g. "Delhi, India" or "29, 77" for lat/long) and click Search. Alternatively, simply scroll around and zoom the map
en click on the desired location.
weden
Search
Latitude
Longitude
55.75
13.25
Parameter:
Maximum Temperature
Chart Type:
Monthly Distribution
Temperature Unit:
Celsius
Map
Satellite
Halmstad
Helsingborg
Kristianstad
Karlshamn
Copenhagen
Lund
Roskilde
Malmö
Ystad
Sjælland
©2017 GeoBasis-DE/BKG (©2009), Google
Terms of Use
Report a map error
Maximum Temperature (Model Monthly Averages).
Latitude: 55.75 & Longitude: 13.25
(°C)
0
5
10
15
20
25
30
35
January
February
March
April
May
June
July
August
September
October
November
December
2071-2099
RCP 6.0 - - - -
RCP 8.5 ——
HadGem
NORES
GFDL
IPCM
MIROC
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.
Home
Your Area
CHIPs
Analysis Tools
Resources
About Us
oday)
or lat/long) and click Search. Alternatively, simply scroll around and zoom the map
Parameter:
Mean Temperature
Chart Type:
Monthly Distribution
Temperature Unit:
Celsius
Mean Temperature (Model Monthly Averages).
Latitude: 55.75 & Longitude: 13.25
(°C)
0
5
10
15
20
25
30
January
February
March
April
May
June
July
August
September
October
November
December
2071-2099
RCP 6.0 - - - -
RCP 8.5 ——
HadGem
NORES
GFDL
IPCM
MIROC
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.

Use statistical theory for extreme events

Law of large numbers

A sample of sample means is Normally distributed

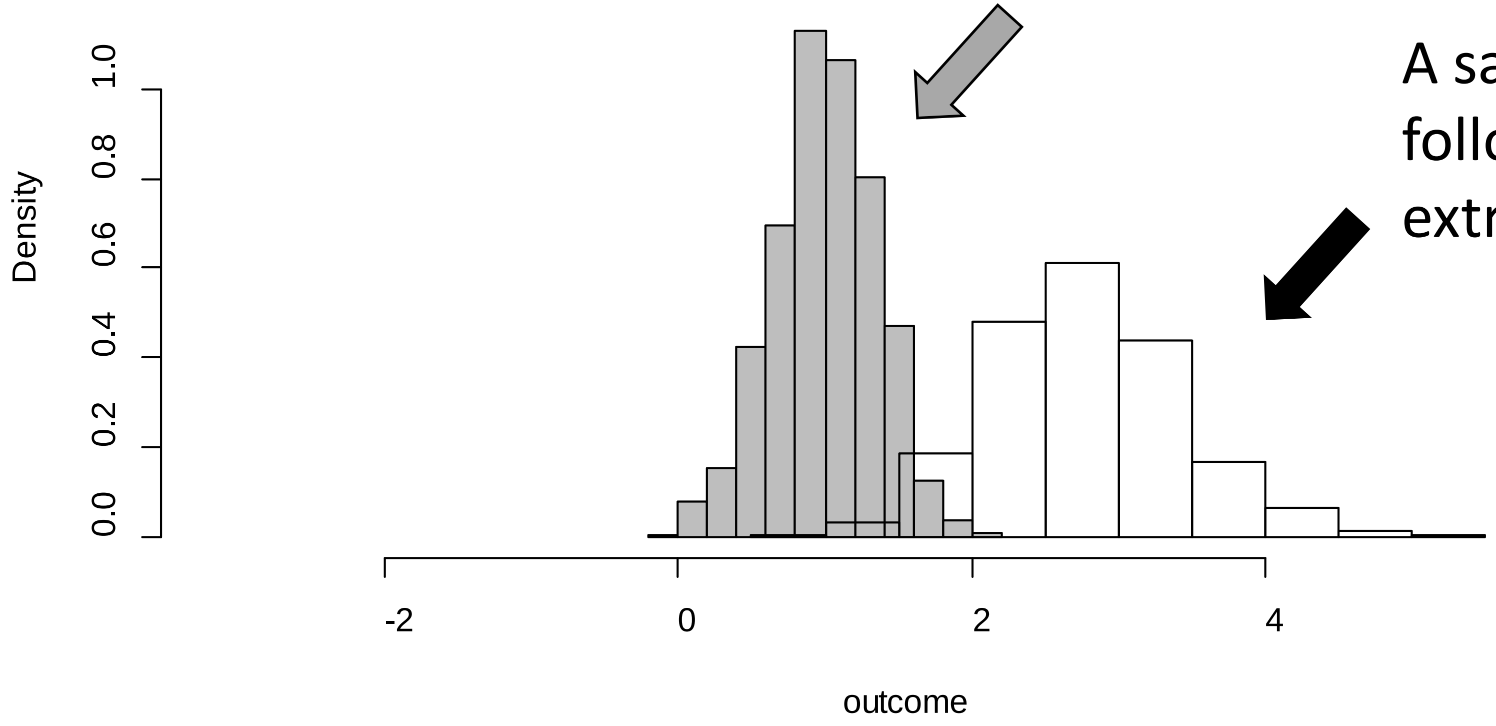


Use statistical theory for extreme events

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

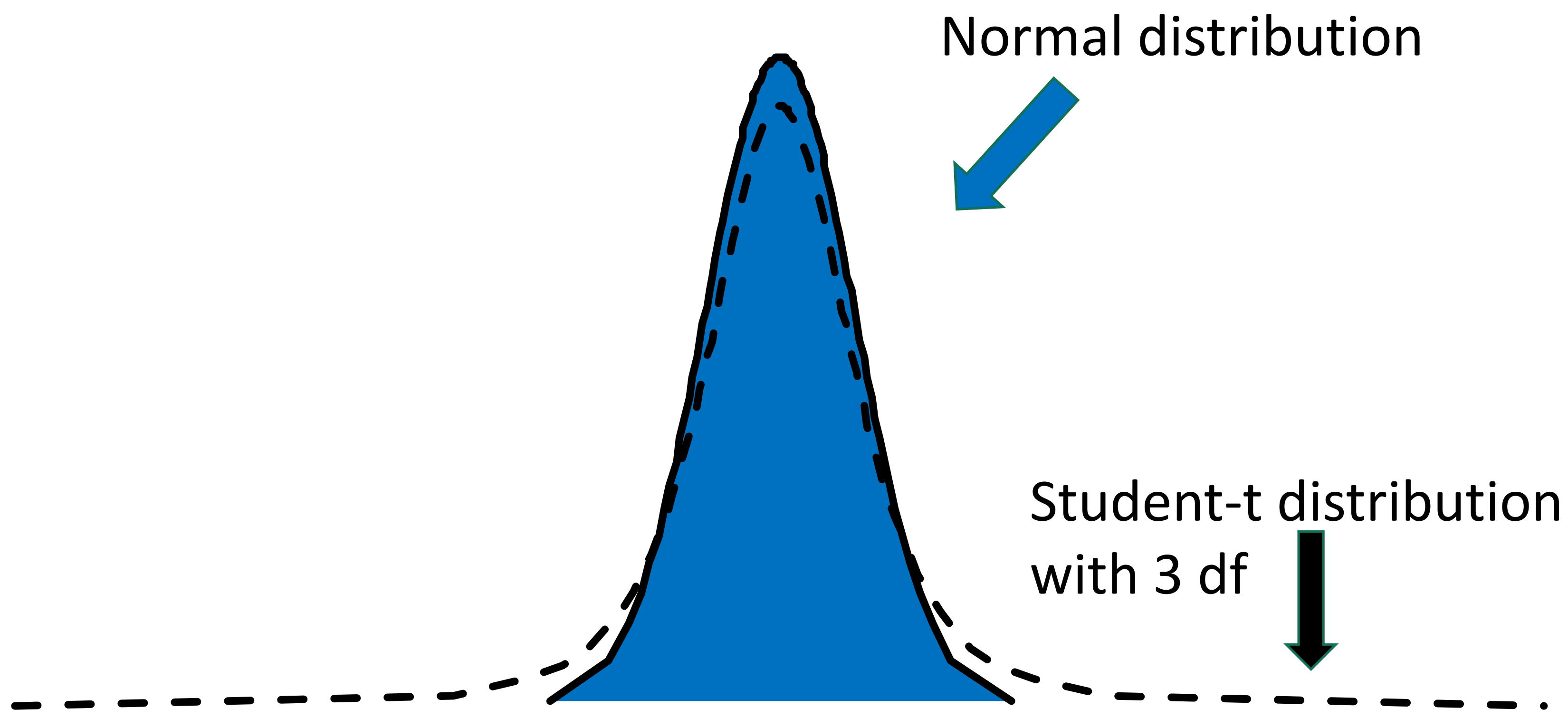
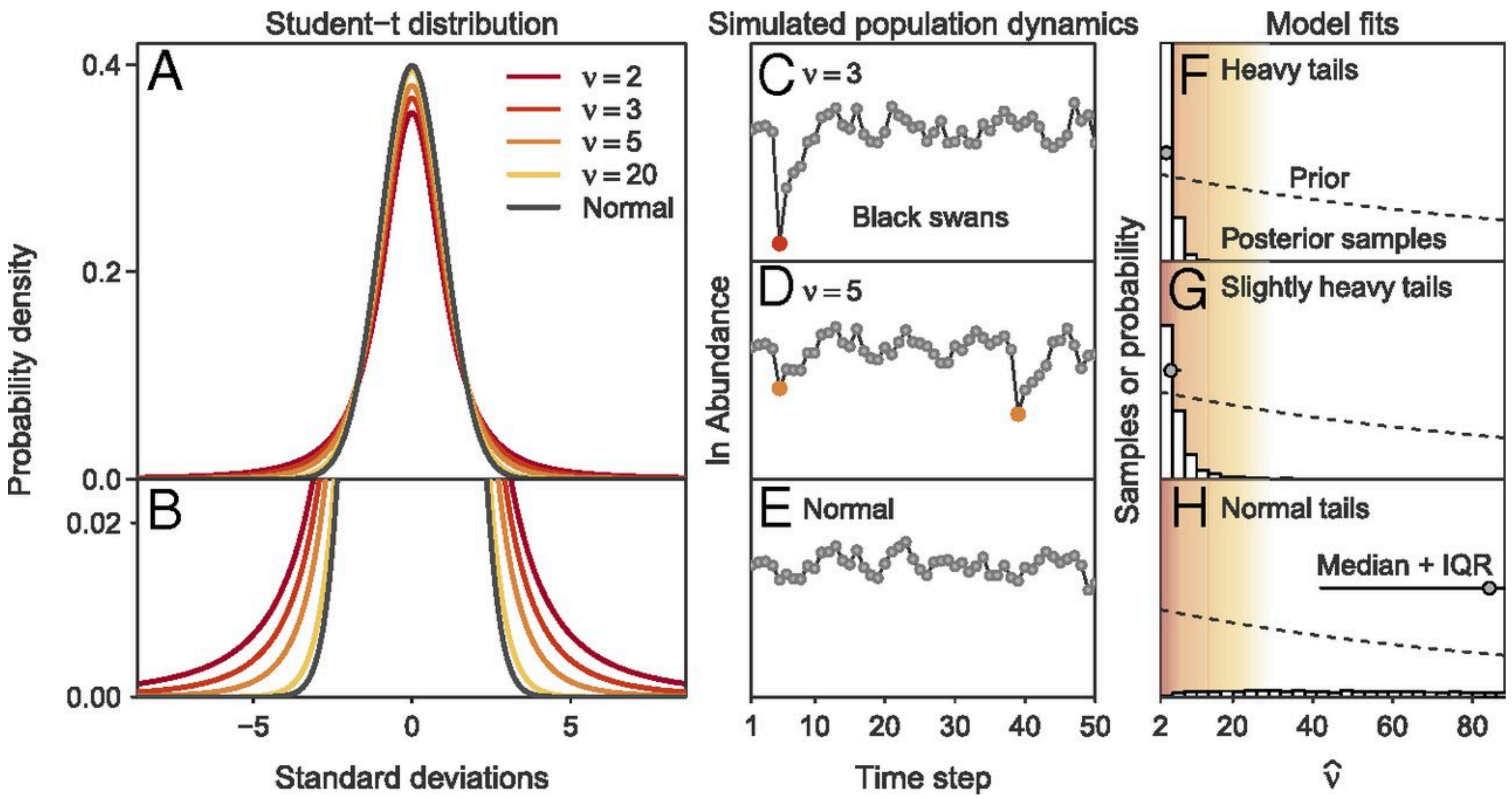


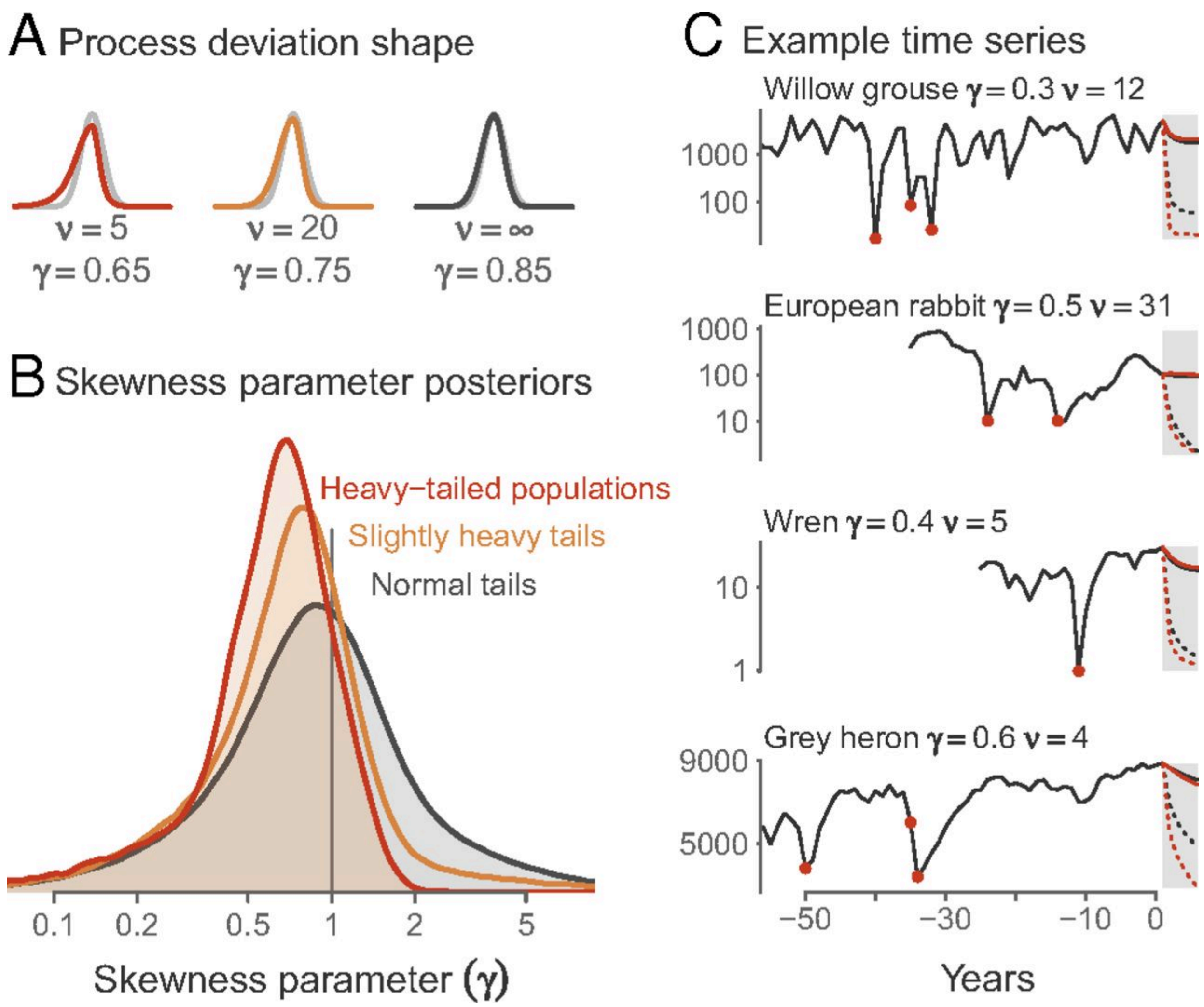
Illustration of population dynamic models that allow for heavy tails



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

PNAS

Ignoring heavy tails can underestimate risk

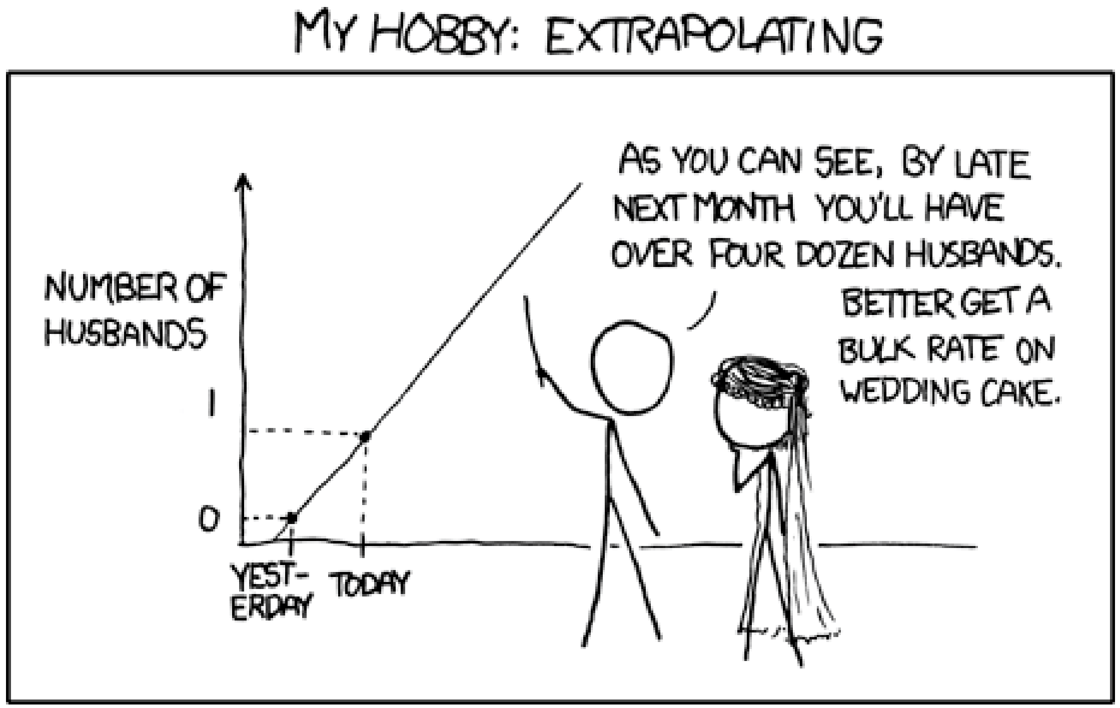


Sean C. Anderson et al. PNAS 2017;114:3252-3257

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.



Consider 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

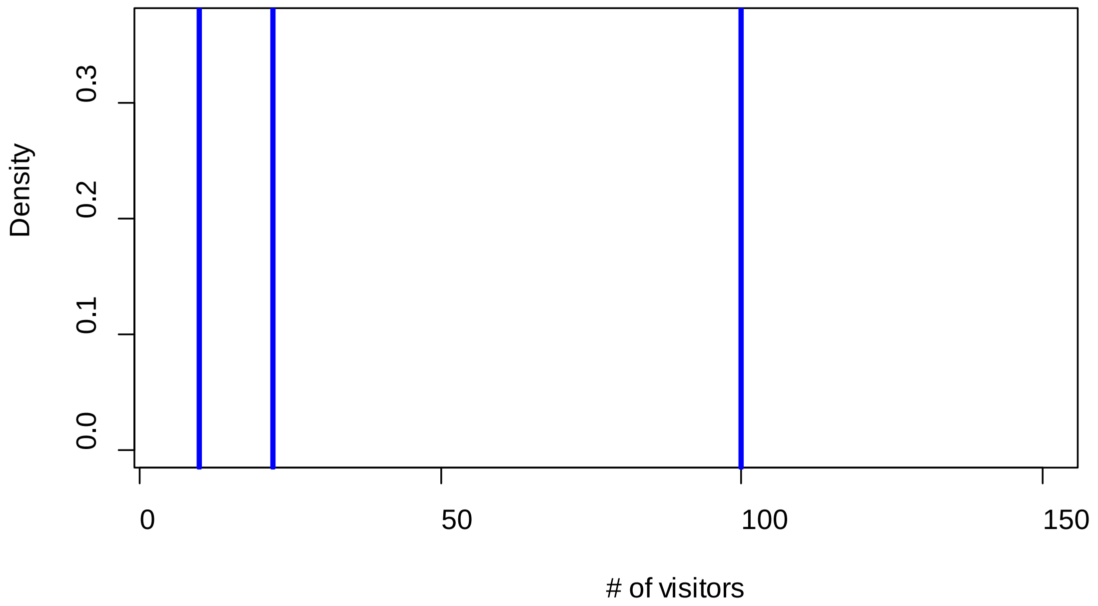
29	13	10	22	45
Birds	Maths	Birds	Maths	Birds
Friday	Friday	Tuesday	Tuesday	Tuesday

LUND UNIVERSITY

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



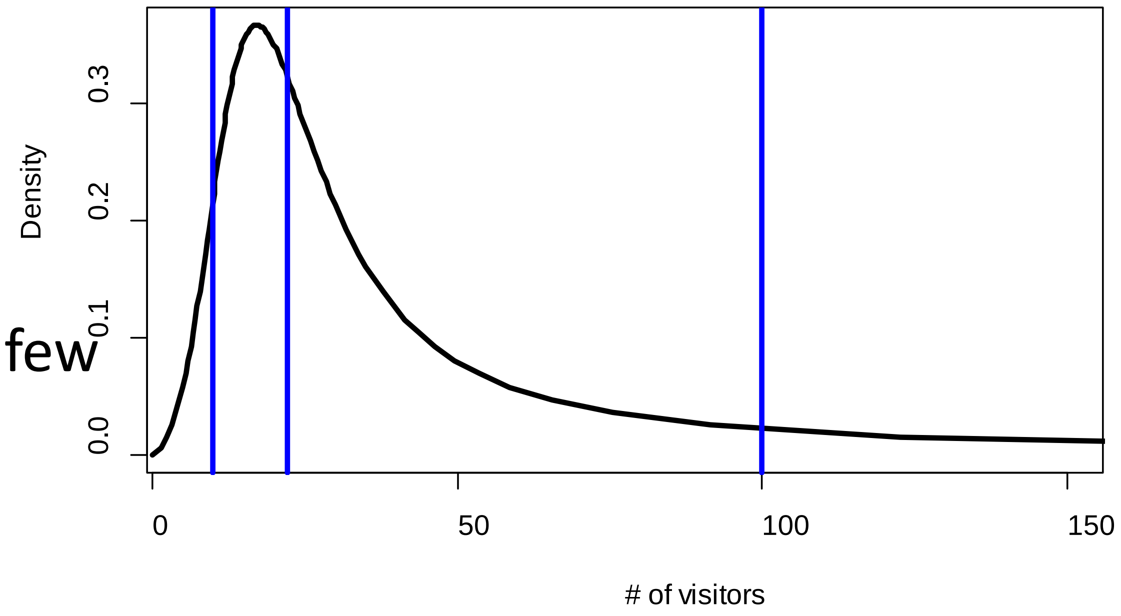
LUND UNIVERSITY

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
  - 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)

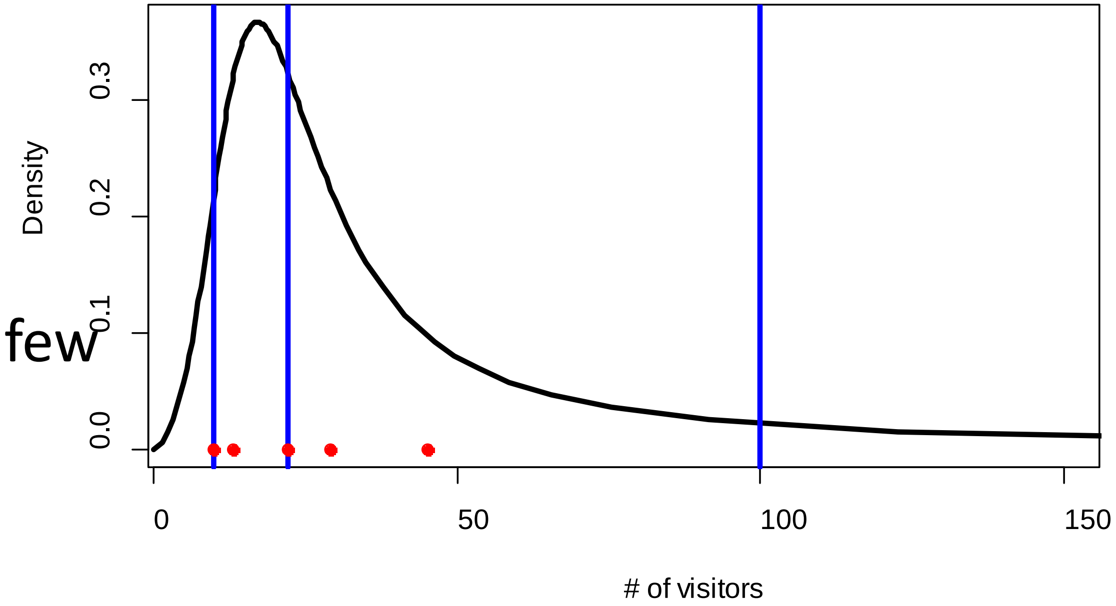


The number of visitors to this lecture

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



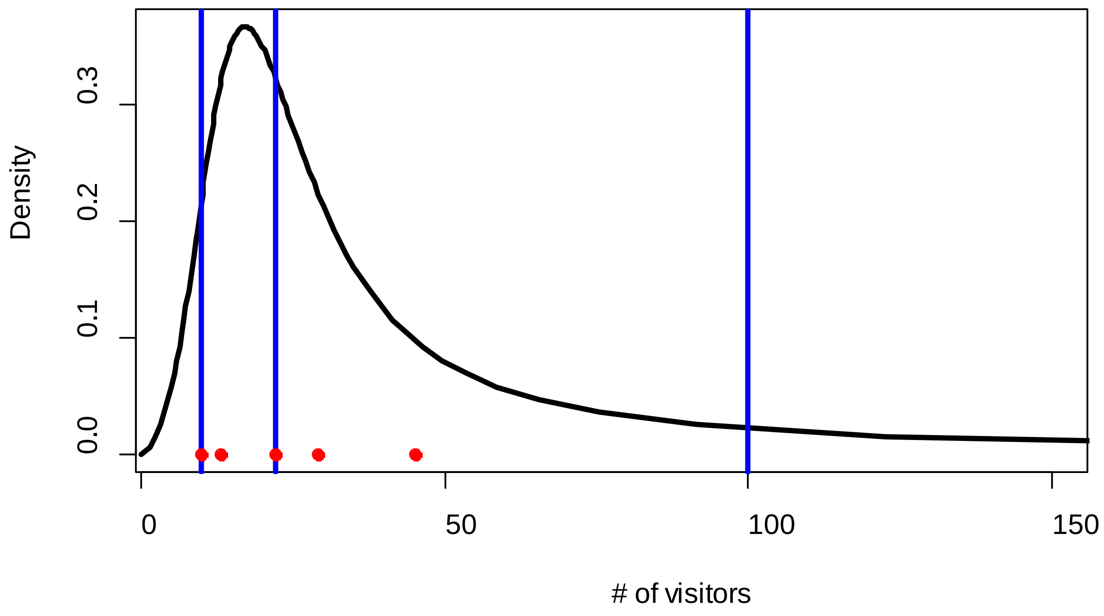
LUND UNIVERSITY

The number of visitors to this lecture

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

LogT(2.84,0.578)



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

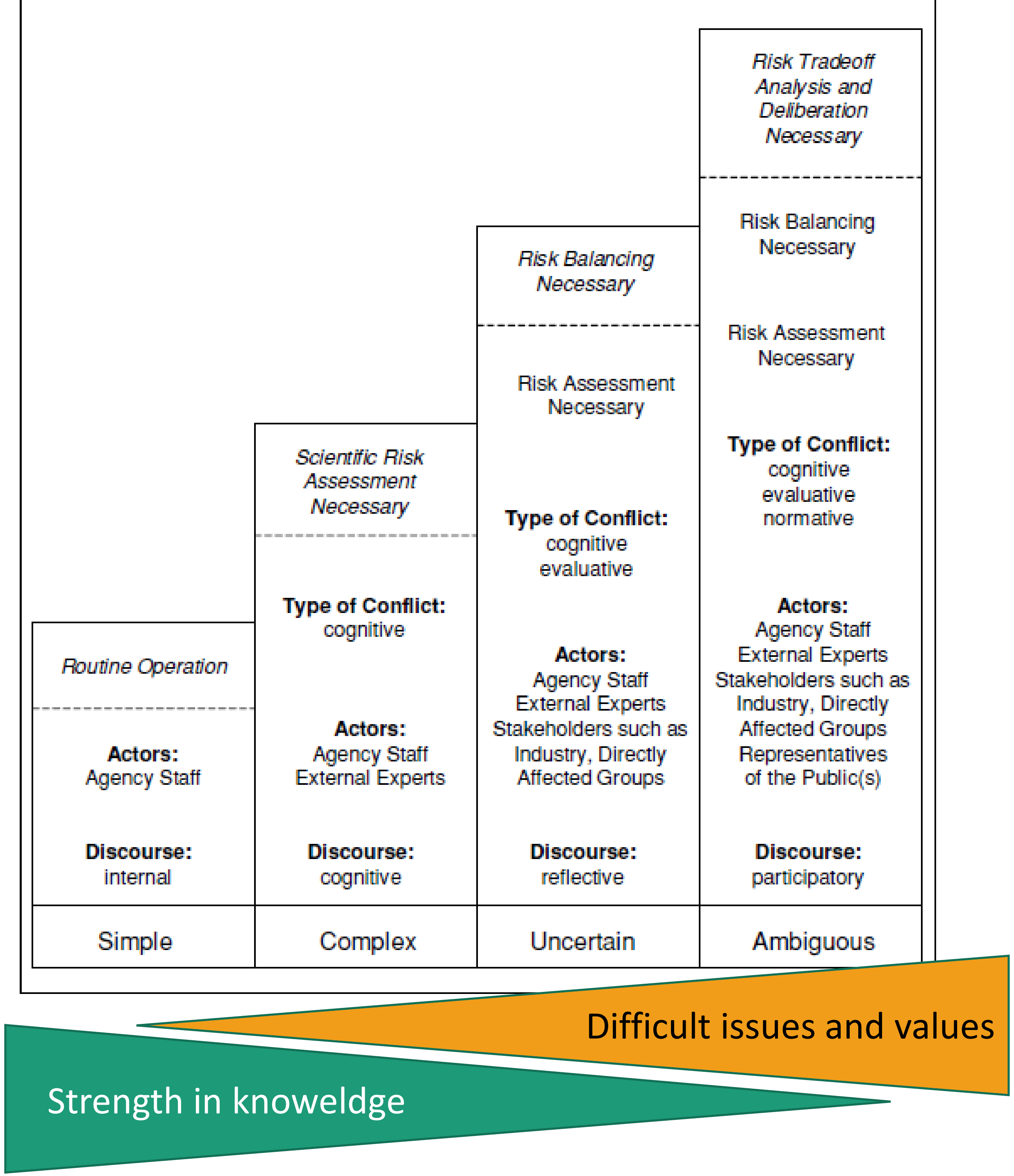
Table 2: Example of quality indicators for scientific evidence (after Bowden, 2004).

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

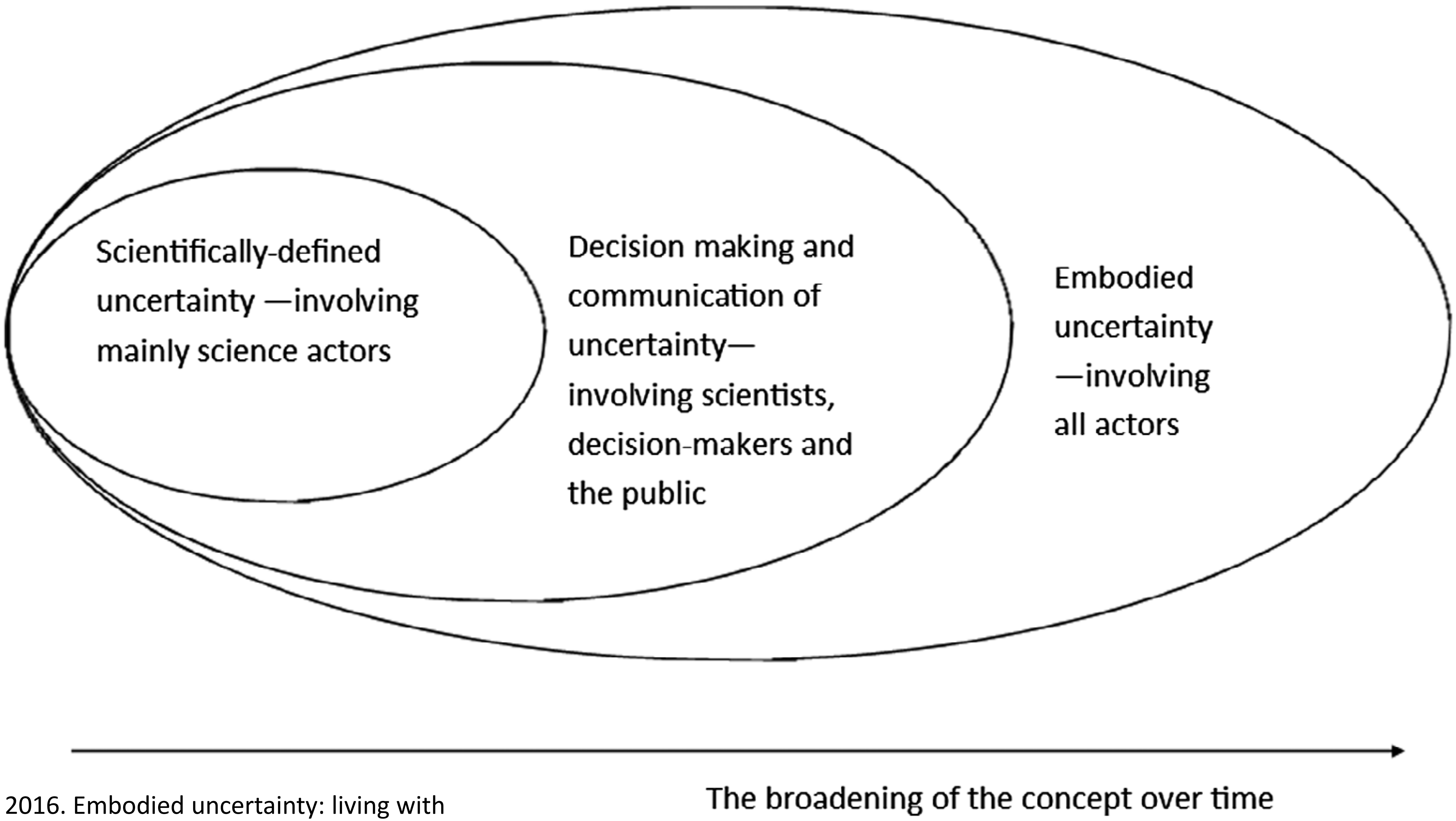
LUND UNIVERSITY

Adapt management

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

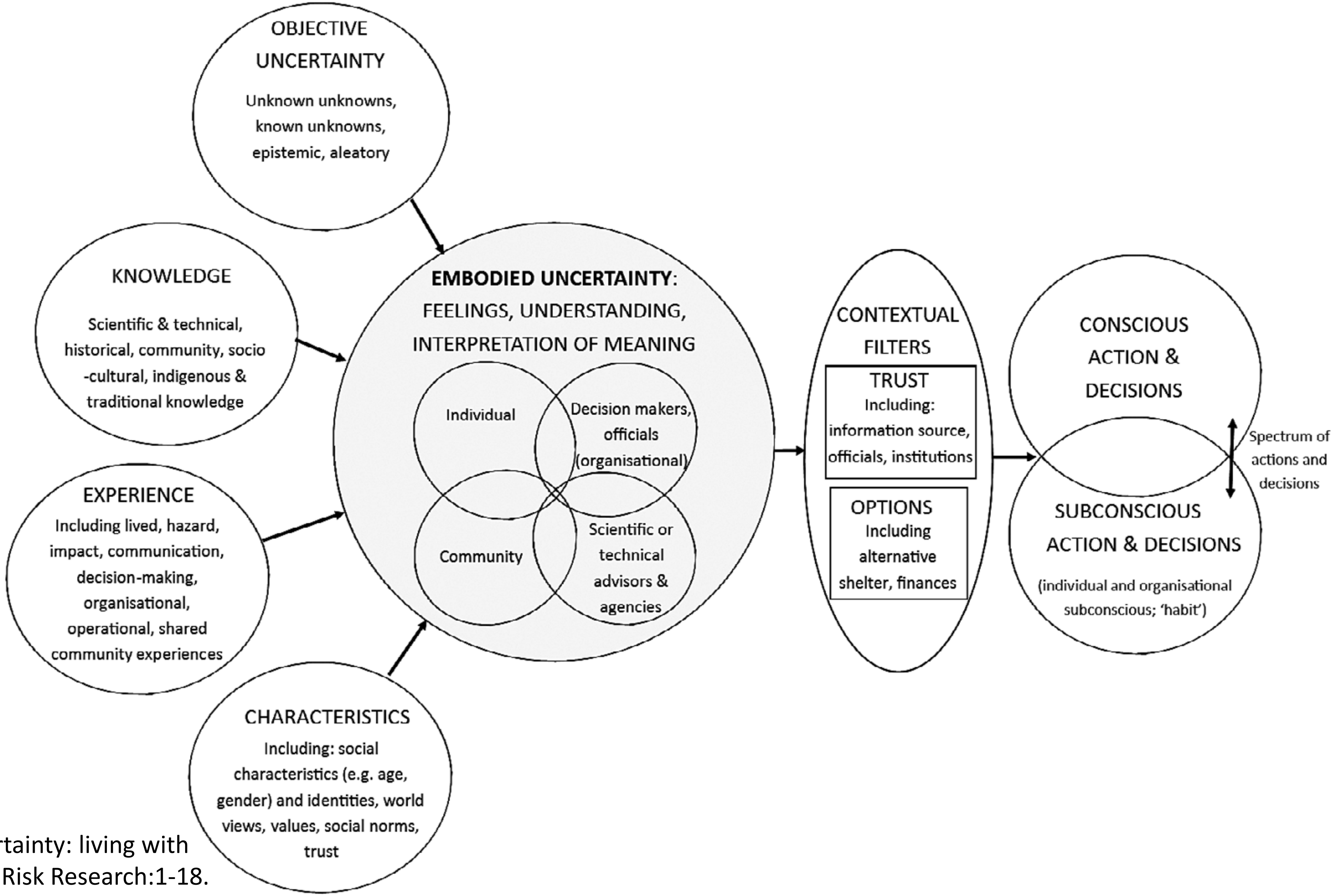


Broaden the uncertainty concept



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.

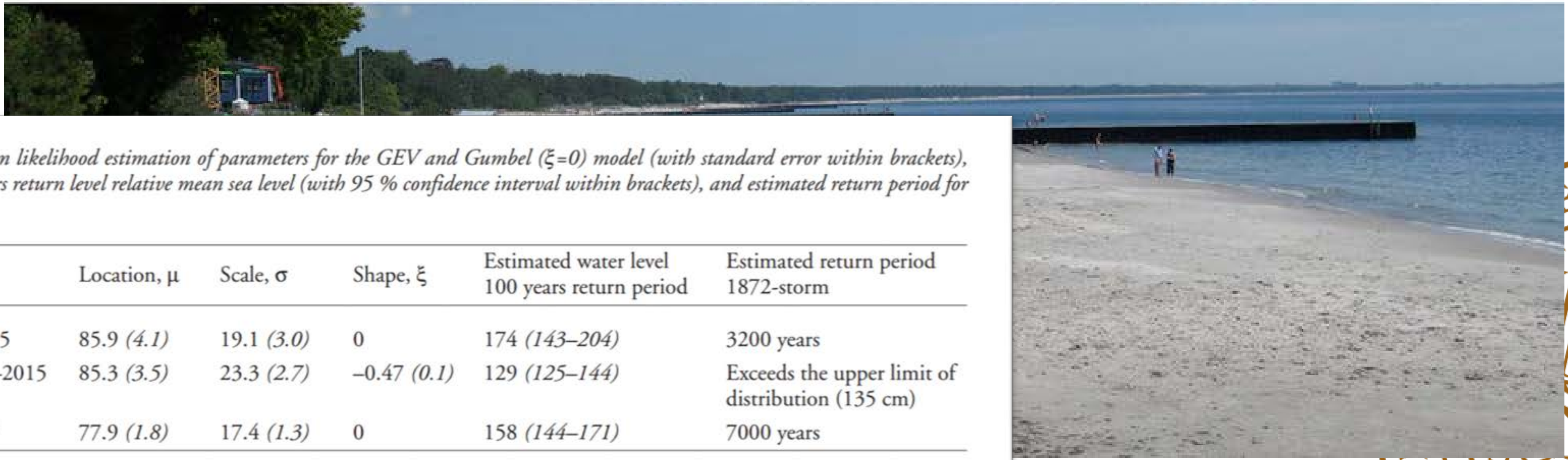


Table 4. *Maximum likelihood estimation of parameters for the GEV and Gumbel (ξ=0) model (with standard error within brackets), estimated 100-years return level relative mean sea level (with 95 % confidence interval within brackets), and estimated return period for the 1872 storm.*

	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