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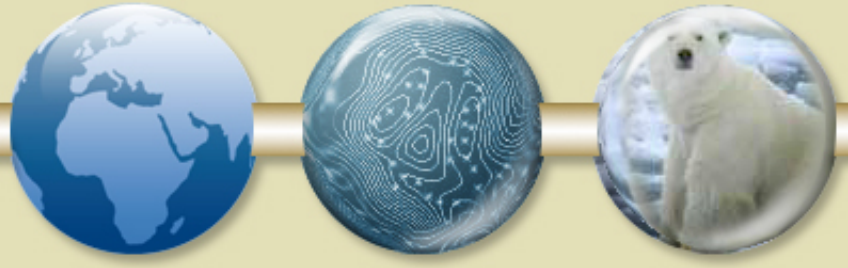

The challenges of analyzing behavioural response study data: An overview of the MOCHA (Multi-study OCean acoustics Human effects Analysis) project

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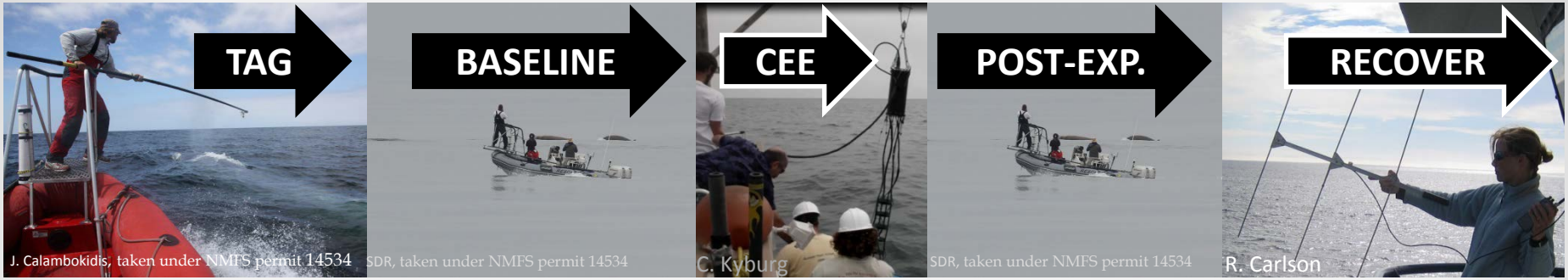
Background



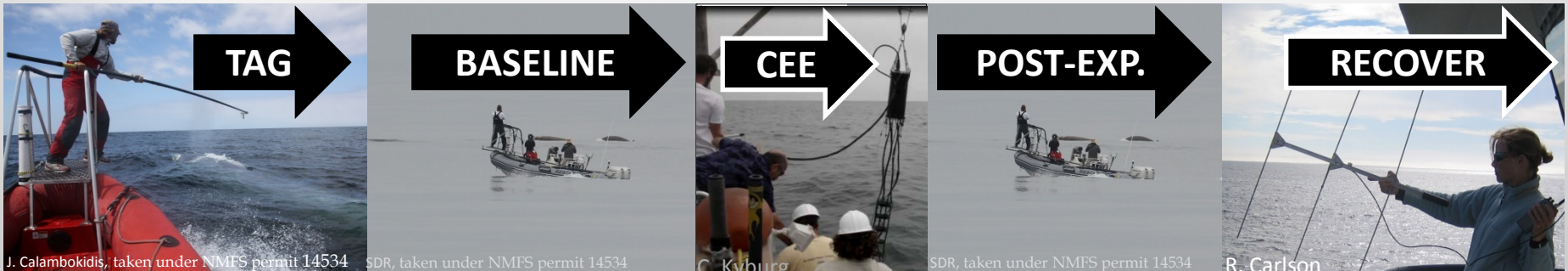
- BRSs can be costly and logistically difficult to undertake
  - low sample sizes
  - few exposures in total
  - fewer individuals.
- However, many diverse measurements on each studied individual
- Traditional statistical methods for analysis do not always
  - make best use of available data
  - capture complexity
  - have enough power to determine a response in all but the most extreme cases.

Analytical challenges

- Large quantity and diversity of data collected through time before, during and after each CEE
  - How do we combine diverse metrics into one measure of response?
  - How do we define and quantify “different” from baseline?
- The context of each CEE differs
  - Does context influence probability of responding?
- We need to relate response to exposure level
  - Can we combine results from individual exposures to estimate a (context-specific) exposure-response function?

MOCHA: Addressing the Challenges

A 3-year (2012-2015(6)) research project that aims to develop and implement innovative methods for the analysis of cetacean behavioural response studies (BRSs).



Aims of MOCHA

- Combining behavioural and/or acoustic measures into a response metric;
- Producing dose-response functions from individual studies;
- Meta-analyses to pool information across studies and species to maximize the gain for each study;
- Sensitivity analyses to quantify where future experimental effort will most reduce uncertainty.

SCOPE

Contributing projects:

- Bahamas BRS (2007-2008)
- SOCAL BRS (2010-2015)
- 3S and 3S2 (2006-2014)
- Duke University BRS (2012-2014)

ADDRESSING THE CHALLENGES

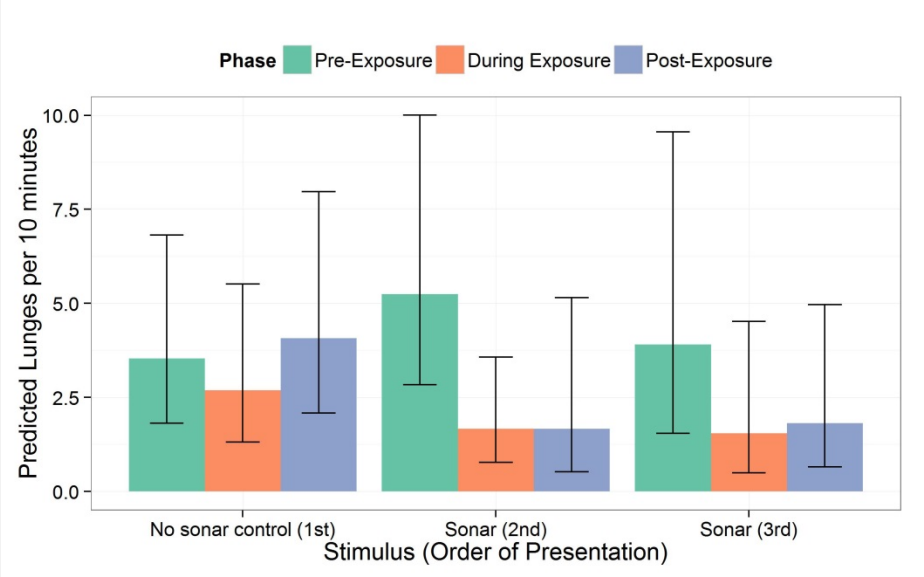
Step 1: Did an animal(s) respond?

- Analysis methods applied/developed:
  - Regression methods, e.g., Generalized estimating equations (GEEs)
  - Change-point analyses, e.g., Mahalanobis distance
  - Process-based time-series models, e.g., Markov models to detect behavioural states and transitions into “disturbed” state

Event rate analysis

Regression methods such as Generalised estimating equations (GEEs) are being used to investigate changes in rates of key behaviours such as lunging and calling in response to sound exposure.

Humpback whale lunging (3S)

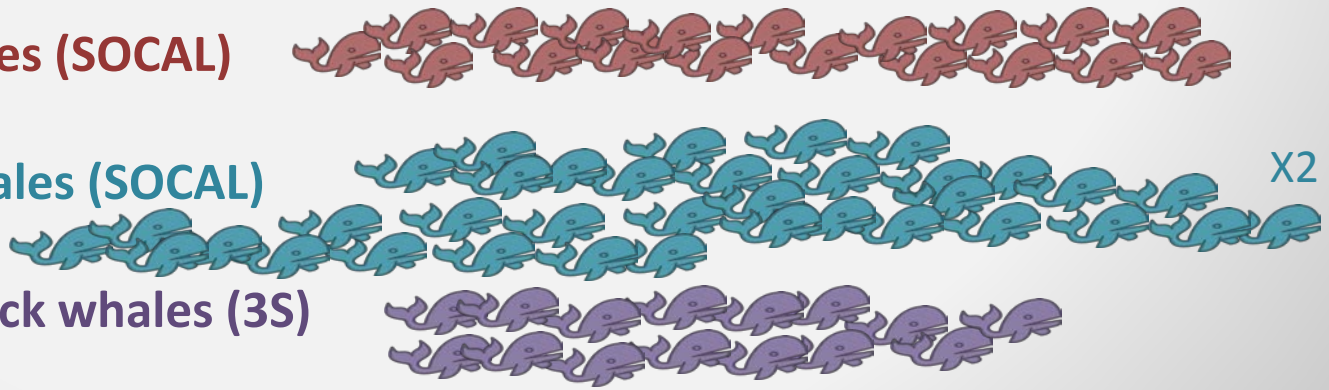


Summary of efforts

- Single species analysis
  - Short-finned pilot whale calling (AUTEC, Cape Hatteras), long-finned pilot whale calling (3S), fin whale calling (SOCAL), humpback lunging (3S), humpback movement (3S)

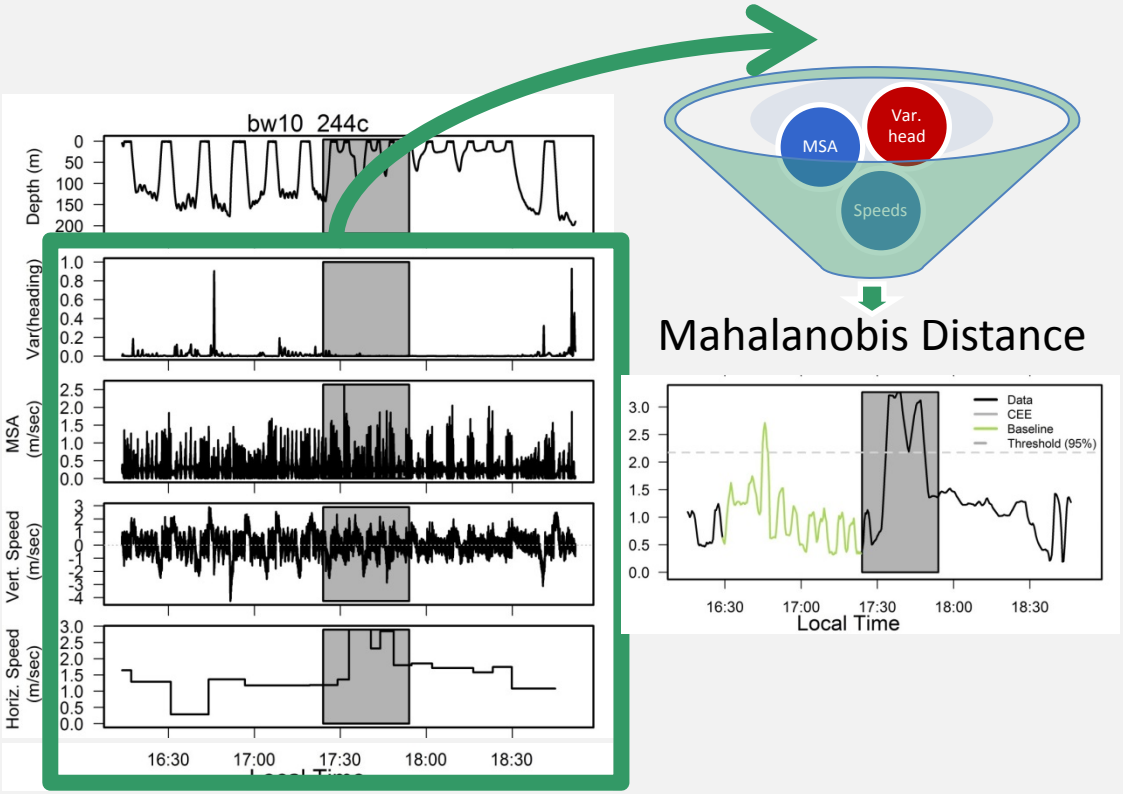
- Multi-species analysis across projects
  - Investigating effect of sonar exposure on lunge rates of baleen whales (MOCHA led)

    - **Fin whales (SOCAL)**
    - **Blue whales (SOCAL)**
    - **Humpback whales (3S)**



Identifying “change-points” using Mahalanobis distance

Md allows us to collapse multivariate time-series into a univariate time-series, and quantify how unusual each dive is compared with baseline.



Antunes et al. (2014). High thresholds for avoidance of sonar by free-ranging long-finned pilot whales (*Globicephala melas*). Marine Pollution Bulletin, 83(1): 165-180.

Miller et al. (2014). Dose-response relationships for the onset of avoidance of sonar by free-ranging killer whales. Journal of the Acoustical Society of America. 135, 975.

DeRuiter et al. (2013) First direct measurements of behavioural responses by Cuvier’s beaked whales to mid-frequency active (MFA) sonar. Biol Lett 9: 20130223.

Summary of efforts

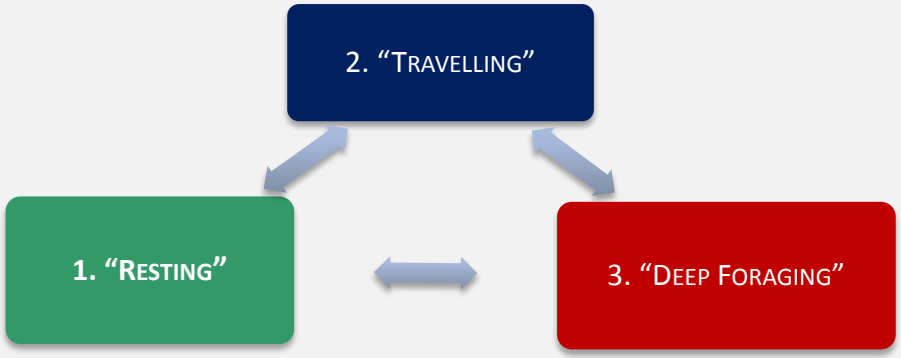
- Single species analysis
  - Cuvier's beaked whale (SOCAL), Baird's beaked whale (SOCAL), northern bottlenose whale (3S), blue whale (SOCAL), long-finned pilot whale (3S), minke whale (3S and SOCAL)

- Joint analysis across projects on minke whales
  - **SOCAL Project** 
  - **3S Project** 

Process-based time-series models

State-switching models (hidden Markov models, semi-Markov models, state-space models), provide an opportunity to explore behavioural states and the probability of transitioning between states as a function of sound exposure

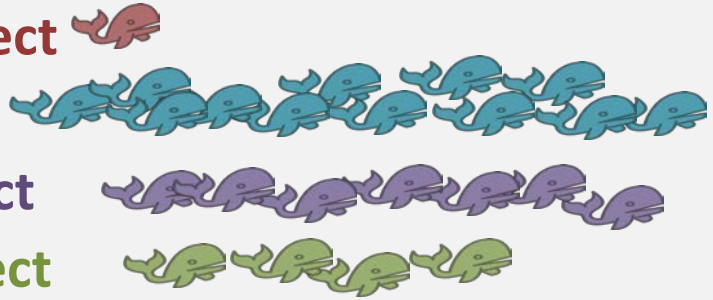
Hidden Markov model for blue whales



Summary of efforts

- Single species analysis
  - blue whales (SOCAL), short-finned pilot whales (Cape Hatteras and AUTEC), long-finned pilot whales (3S) sperm whales (3S), humpback whales (3S)

- Multi-species analysis across projects
  - semi-Markov model for sperm whale foraging behavior (MOCHA led)
    - **SOCAL Project**
    - **3S Project**
    - **SWSS Project**
    - **Sirena Project**

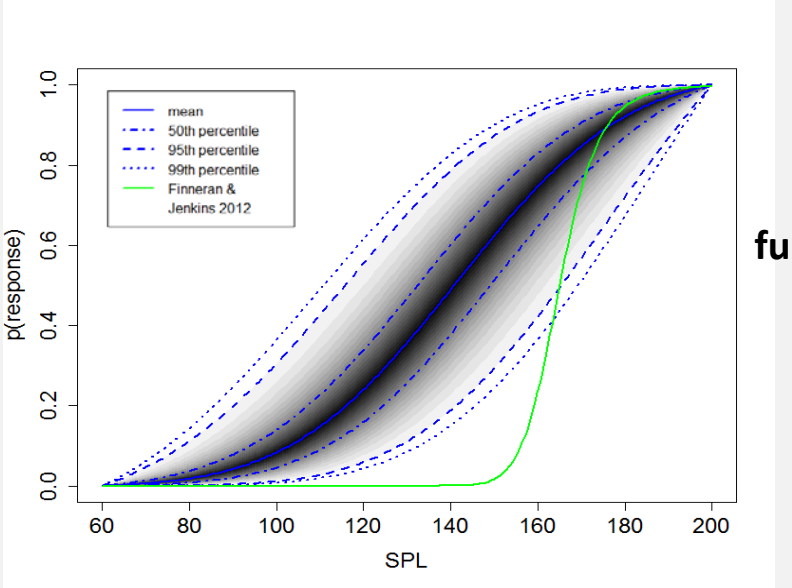


Step 2 - relate responses to dose

- Analysis methods applied/developed
  - Bayesian hierarchical dose-response models
  - Cox proportional hazards models for dose-response severity functions

Bayesian hierarchical dose-response analysis

These models fit a relationship between exposure (received level) and behavioural response, taking account of within and between-whale variation, contextual covariates and instances where individuals did not respond (censored data)



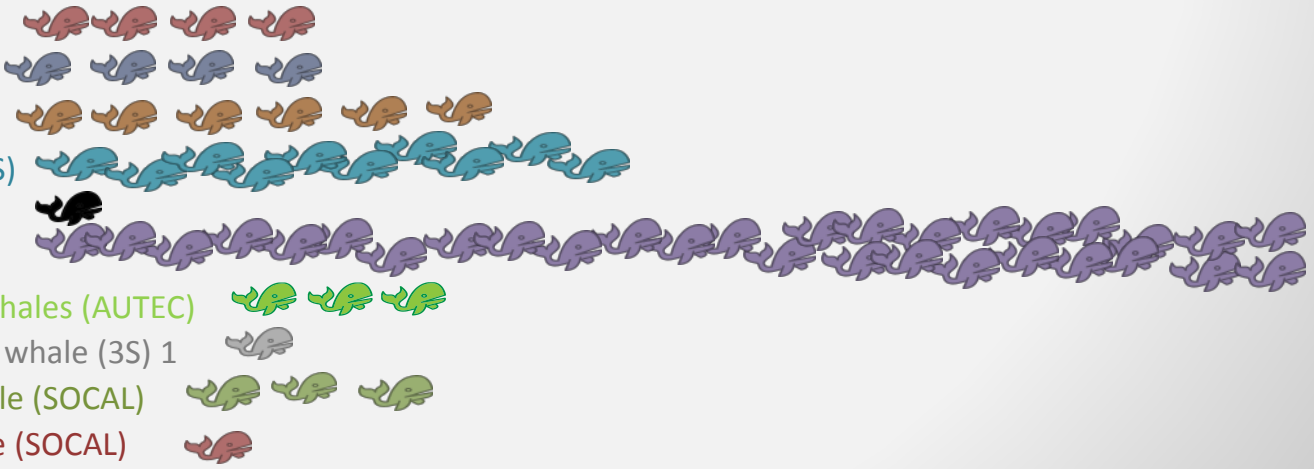
Killer whale dose-response function for the onset of avoidance in relation to MFAS or LFAS exposure

Miller et al. (2014). Dose-response relationships for the onset of avoidance of sonar by free-ranging killer whales. Journal of the Acoustical Society of America.

Summary of efforts

- Single species analysis of avoidance responses
  - killer whales (3S (Miller et al. 2014)), long-finned pilot whales (3S (Antunes et al. 2014)), humpback whales (3S)

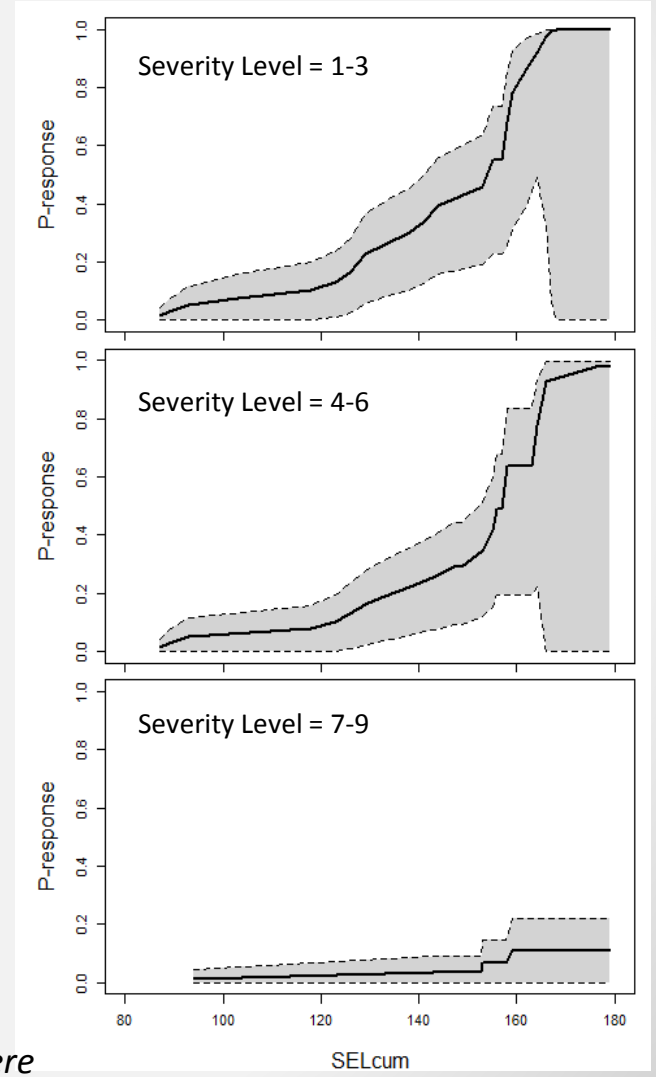
- Multi-species analysis of avoidance responses across projects (MOCHA led)
  - sperm whales (3S)
  - killer whales (3S)
  - pilot whales (3S)
  - Humpback whale (3S)
  - minke whale (3S)
  - blue whales (SOCAL)
  - Blainville's beaked whales (AUTEC)
  - northern bottlenose whale (3S) 1
  - Cuvier's beaked whale (SOCAL)
  - Baird's beaked whale (SOCAL)



Dose-response severity analysis

Recurrent event analysis (example shows function for killer, sperm and pilot whales combined)

Cox proportional hazards models (time to event models) have been used to fit a relationship between received acoustic energy (cumulative SEL) and response events of different severities, accounting for contextual covariates and censored data points



Harris et al. (*2015*). Dose response severity functions for acoustic disturbance in cetaceans using recurrent event survival analysis. *Ecosphere*

Summary of efforts

- Single species analysis across projects
  - killer whales (3S), long-finned pilot whales (3S), sperm whales (3S), blue whales (SOCAL), humpback whales (3S)

- Multi-species analysis within 3S project
  - Harris et al. (2015)
    - Killer whales 
    - sperm whales 
    - pilot whales 

Harris et al. (*2015*). Dose response severity functions for acoustic disturbance in cetaceans using recurrent event survival analysis. *Ecosphere*.

Summary of BRSs

- Large and complex suite of data streams
- Small numbers of exposures and even smaller numbers of individuals
- Challenges include
  - producing manageable and interpretable metrics for analysis
  - conducting analysis appropriate for small sample sizes
  - placing the results into context.
- We (BRS project teams and MOCHA) have made significant steps in addressing these challenges

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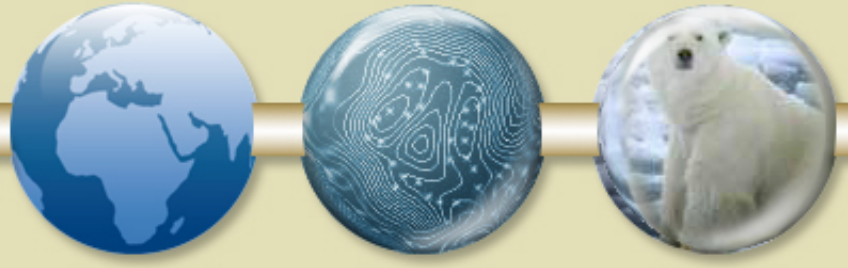

- Project website - http://www.creem.st-and.ac.uk/mocha/
- Working group meeting reports - http://www.creem.st-and.ac.uk/mocha/project-outputs
- E.mail address – mocha@st-andrews.ac.uk

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