Modelling, Computer Architecture and Physical Processes

Group Summary

Topic 1 – Storm tracks

Develop predictive theories for storm track response to external forcing

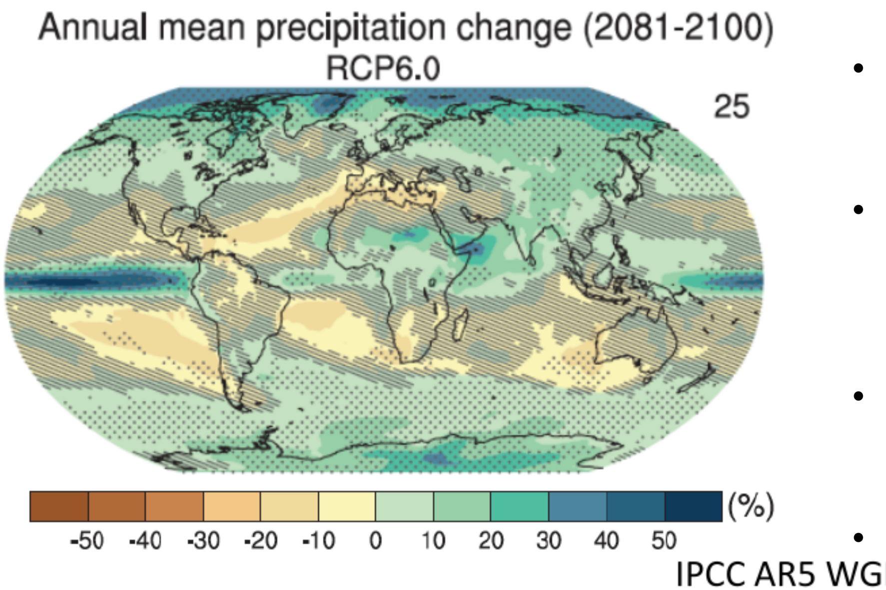


Figure - Annual mean precipitation change for the end of the 21st century for an ensemble of CMIP5 climate models. Stippled (robust changes); Hatched (changes smaller than natural variability); No marks (inconsistent model response). From Knutti and Sedlacek (2013)

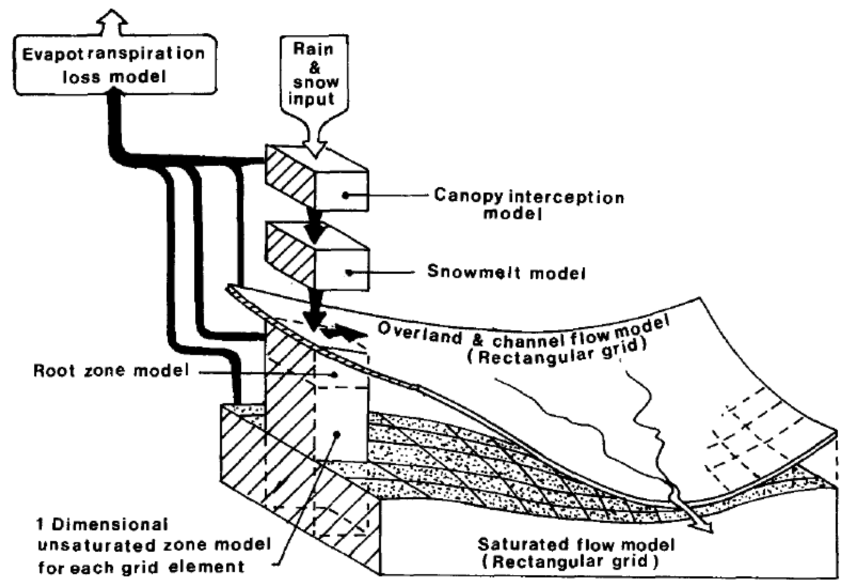
- Extreme meteorological events are related to the position and intensity of the jet streams and storm tracks.
- Regions that do not show a robust response to radiative forcing have been tied to dynamical aspects of climate change (Figure)
- Storm tracks depend on internal atmospheric dynamics and boundary conditions (SST, sea ice).
- Given the complexity of the problem, <u>there is a need to tackle it using a hierarchy of climate models.</u>
- Develop process-based metrics based on the known theory, to diagnose the behavior. Then use the hierarchy of models to develop an understanding and predictive theory
- Data-driven research can also help if it is connected to physical understanding.

Topic 2 – Hydrological modeling

Hydrological Modelling

Motivation

- Siltation of reservoirs;
- Simulation of sediment transport;
- Distribution of land-use and soil properties;
- Distribution of precipitation, temperature and other variables;
- Water is a crucial resource for hydro-power.



Current practice

- Use of probability distributed model;
- Fast reasonable prediction, easy to use, not data demanding;
- Doesn’t account for many processes (precipitation, etc.);
- Cannot simulate sediment transport;
- Does not include land-use change;

New techniques

- Other models exist that account for additional processes but are prohibitive due to computational cost;
- Can we reduce complexity of these models so that they can be run during the operational window?
- Need to study new numerical schemes that allow for easy, efficient parallelisation.

Topic 3 – Landslides

Introduction

- The monitoring of mass movement systems is one of the objectives of CEMADEN's natural hazards alert system.

- Although many events are triggered by rain, the distribution of geological structures and layers has a key role in the landslide event.

- For this reason CEMADEN is implementing a system integrated to the SALVAR system for the monitoring of the underground water content in several critical areas in Brazil.

Equipment and Data Aquisition

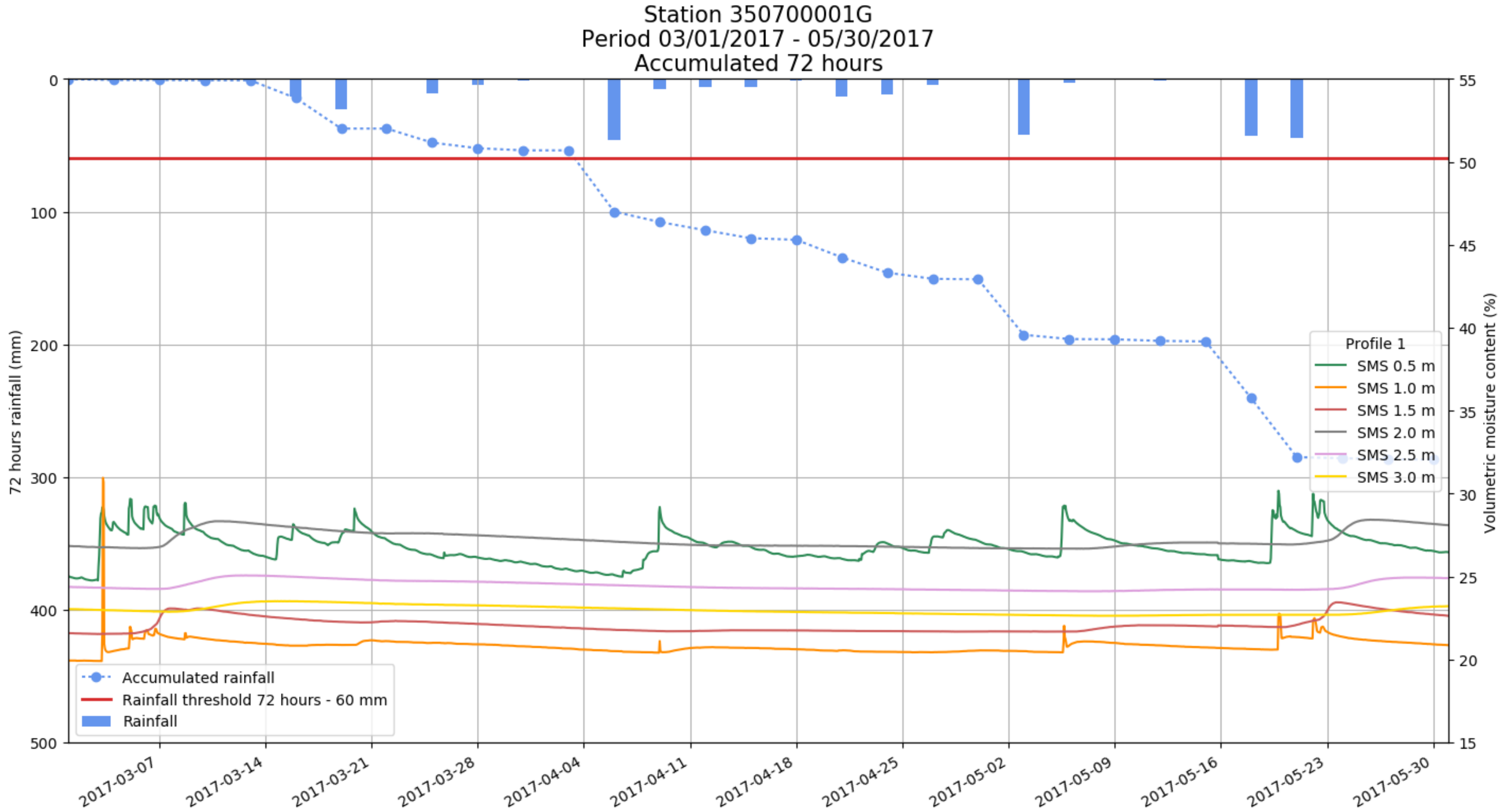
- The equipment corresponds to a pluviometer station coupled to sensors installed in wells that measure the humidity every 0.5m.
- The humidity values are acquired every hour in times without rain and every 10 minutes during the rainy period, with the sampling change done automatically.
- Some stations are already operating in Campos do Jordão for the last 2 years.
- During the drilling of the well, where the sensors go, a distribution of the geological layers is already obtained at that point.
- In addition, geophysical acquisitions are planned with the Resistivity and Inductive Electromagnetic methods in the station areas to determine the 2D variation of subsurface structures.

What we have now?

- The initial use of the stations is to have a constant monitoring in the Situation Room, with the average values of humidity, critical values of humidity that produce a rupture and the current value of humidity. With an automatic warning when moisture values change rapidly.

- This system is still being developed and is not yet operational at CEMADEN. Although the system allows instantaneous visualization of the humidity in different layers in real time, its use for alert is restricted, once the alert will be in very short notice.

Data



Station 350700001G
Period 03/01/2017 - 05/30/2017
Accumulated 72 hours
72 hours rainfall (mm)
Volumetric moisture content (%)
Profile 1
SMS 0.5 m
SMS 1.0 m
SMS 1.5 m
SMS 2.0 m
SMS 2.5 m
SMS 3.0 m
Accumulated rainfall
Rainfall threshold 72 hours - 60 mm
Rainfall
2017-03-07
2017-03-14
2017-03-21
2017-03-28
2017-04-04
2017-04-11
2017-04-18
2017-04-25
2017-05-02
2017-05-09
2017-05-16
2017-05-23
2017-05-30

Project

- Associate the rain forecast and the current situation of the geological layers humidity to predict a possible rupture situation due the stability deterioration caused by the accumulation of water in the underground.

Main Objectives

- Understand how geotechnical parameters (for example, hydraulic conductivity, porosity, permeability, chemical composition) can be associated with geophysical parameters (for example, electrical resistivity, magnetic susceptibility).

- Determine how the water content in the layers is related to the amount and intensity of rainfall.

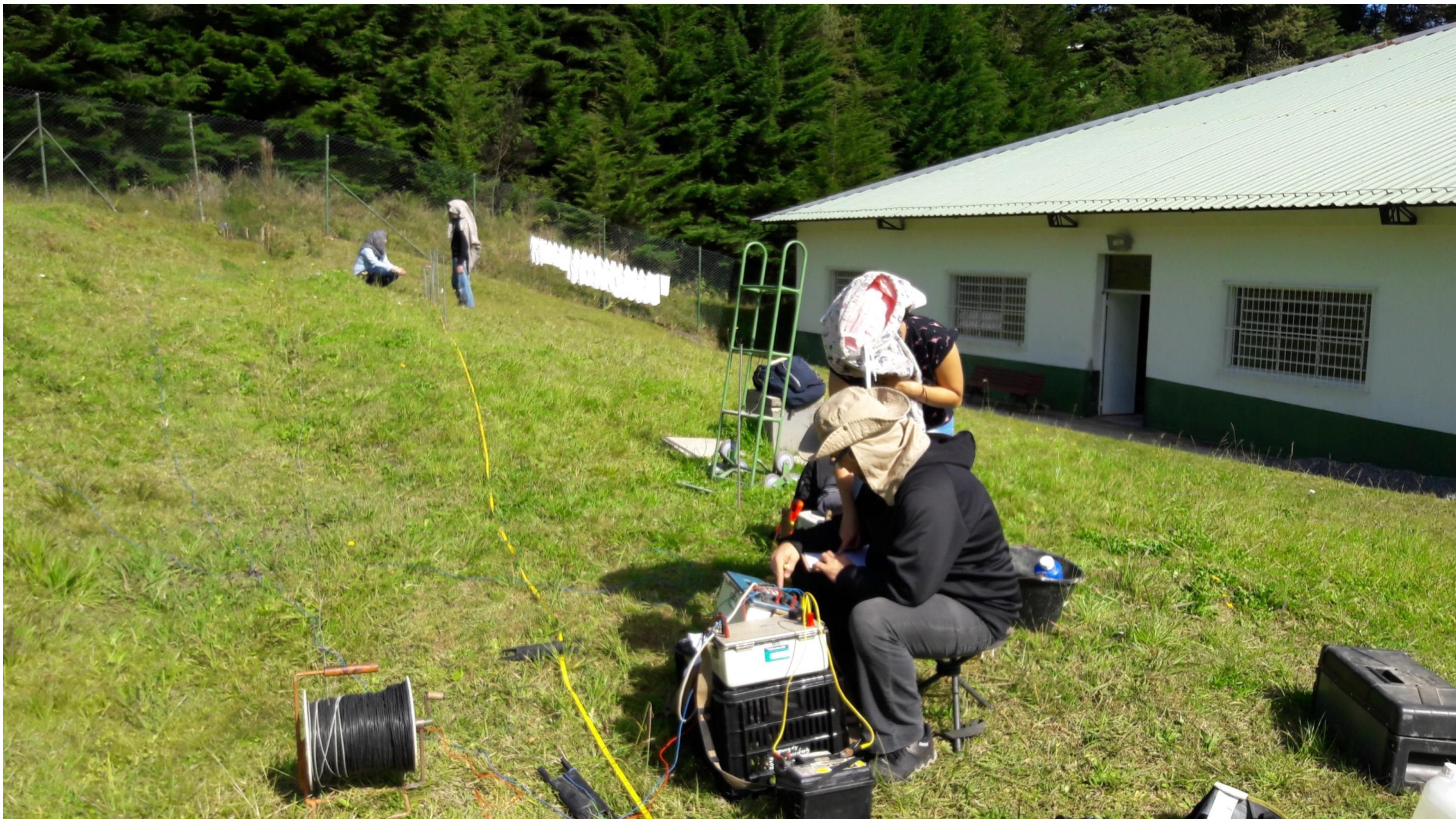
- Predict how the expected rainfall will change the soil humidity.

- Determine if with the expected humidity will have the occurrence of landslides.

The Challenges

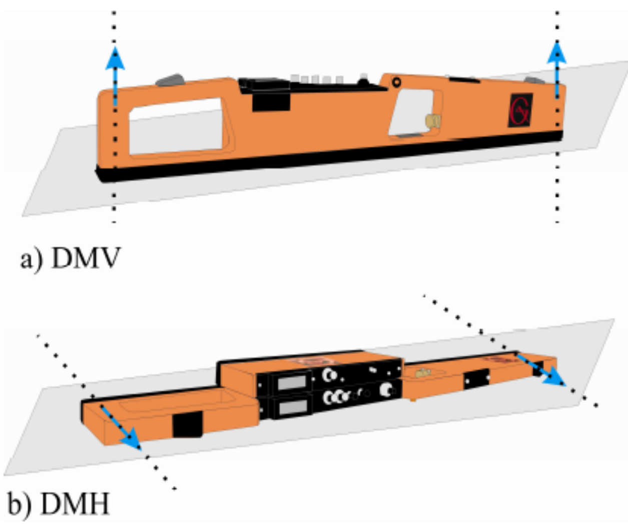
- There are some equations and procedures to associate geotechnical parameters to geophysical parameters, but not many are addressed to the problem of landslides.
- To understand the relationship between rain intensity and the water content of the layers, a numerical modeling process is required.
- The prediction of how future rainfall will influence the soil moisture of the layers should be made in conjunction with future weather forecasting.
- The modeling of how future rainfall will influence the hydrogeodynamic balance of the areas should be done automatically or semi-automatically.
- In CEMADEN, the softwares that models the hydrogeodynamic balance of the slopes are GeoSlope and GeoStudio. That way the whole process is done as a black box and cannot be changed for the proposed goals.

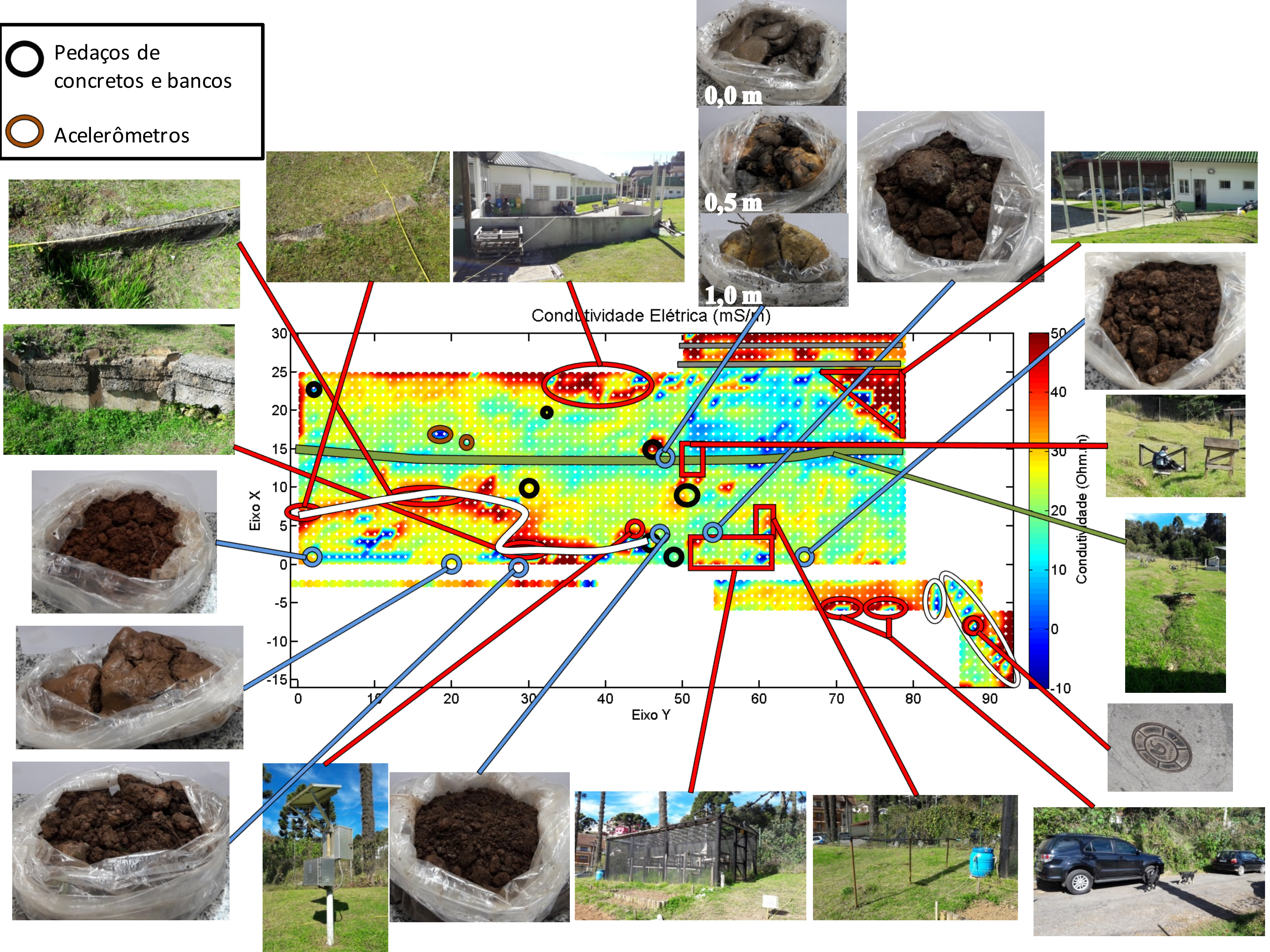
Eletrorresistividade

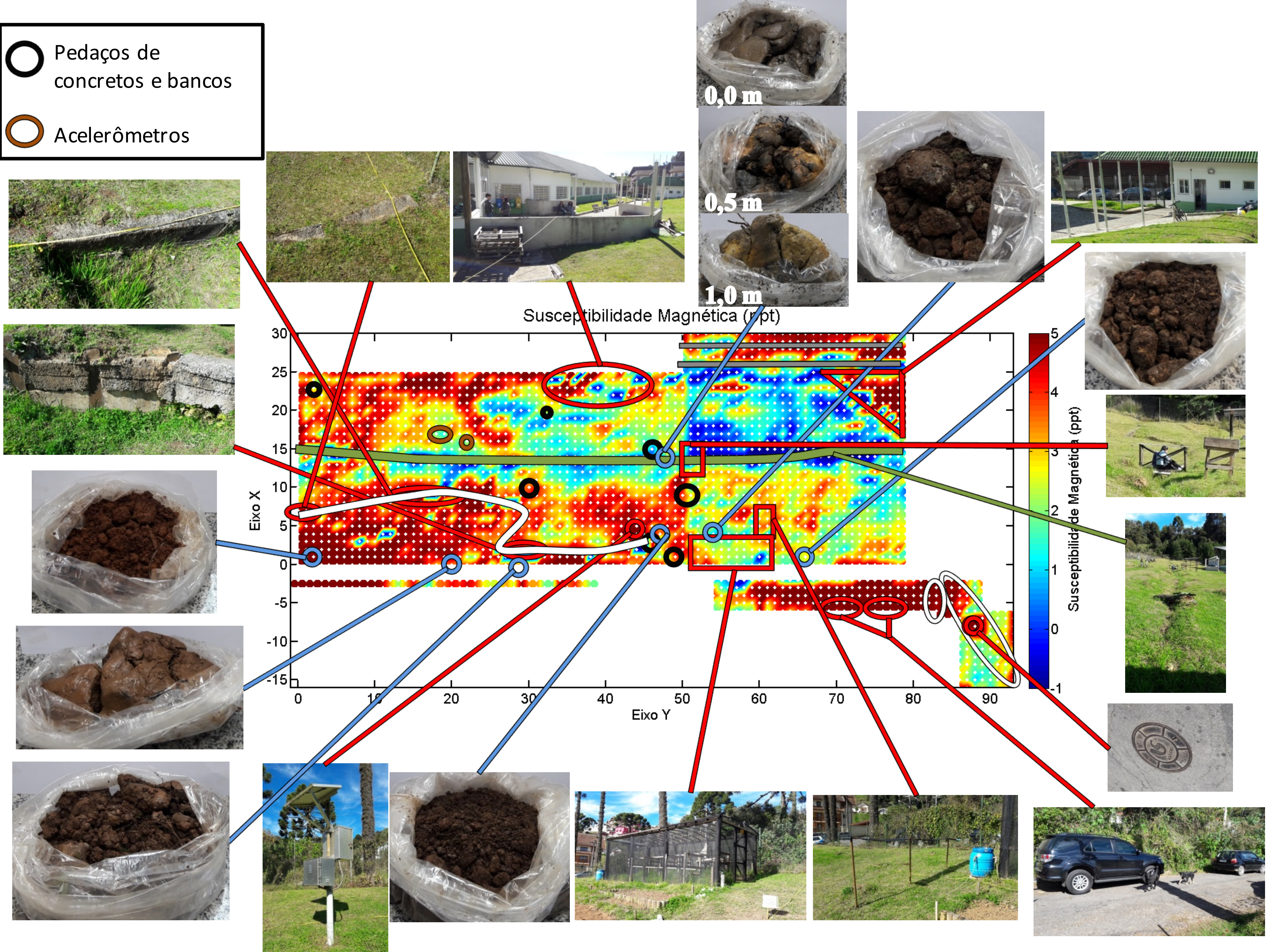


EM38

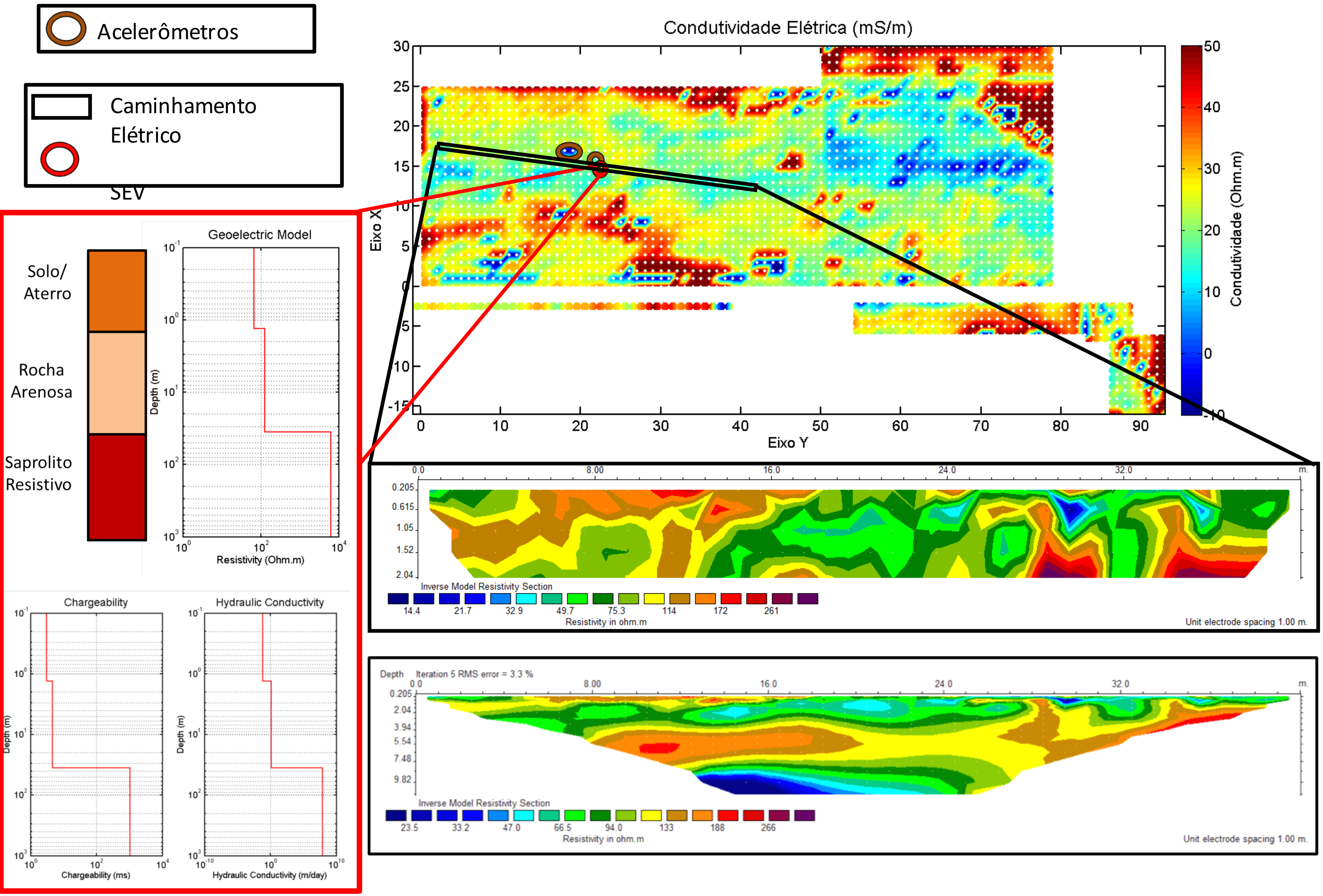
Figura 3.3: Equipamento EM38 (Geonics Ltd.).




Pedaços de concretos e bancos
Acelerômetros
0,0 m
0,5 m
1,0 m
Condutividade Elétrica (mS/m)
Eixo X
Eixo Y
Condutividade (Ohm.m)
30
25
20
15
10
5
0
-5
-10
-15
0
10
20
30
40
50
60
70
80
90
50
40
30
20
10
0
-10



Pedaços de concretos e bancos
Acelerômetros
0,0 m
0,5 m
1,0 m
Susceptibilidade Magnética (ppt)
Eixo X
Eixo Y
Susceptibilidade Magnética (ppt)



Acelerômetros
Caminhamento Elétrico
SEV
Condutividade Elétrica (mS/m)
Eixo X
Eixo Y
Condutividade (Ohm.m)
Solo/ Aterro
Rocha Arenosa
Saprolito Resistivo
Geoelectric Model
Depth (m)
Resistivity (Ohm.m)
Chargeability
Chargeability (ms)
Hydraulic Conductivity
Hydraulic Conductivity (m/day)
Inverse Model Resistivity Section
Resistivity in ohm.m
Unit electrode spacing 1.00 m.
Depth Iteration 5 RMS error = 3.3 %
Inverse Model Resistivity Section
Resistivity in ohm.m
Unit electrode spacing 1.00 m.

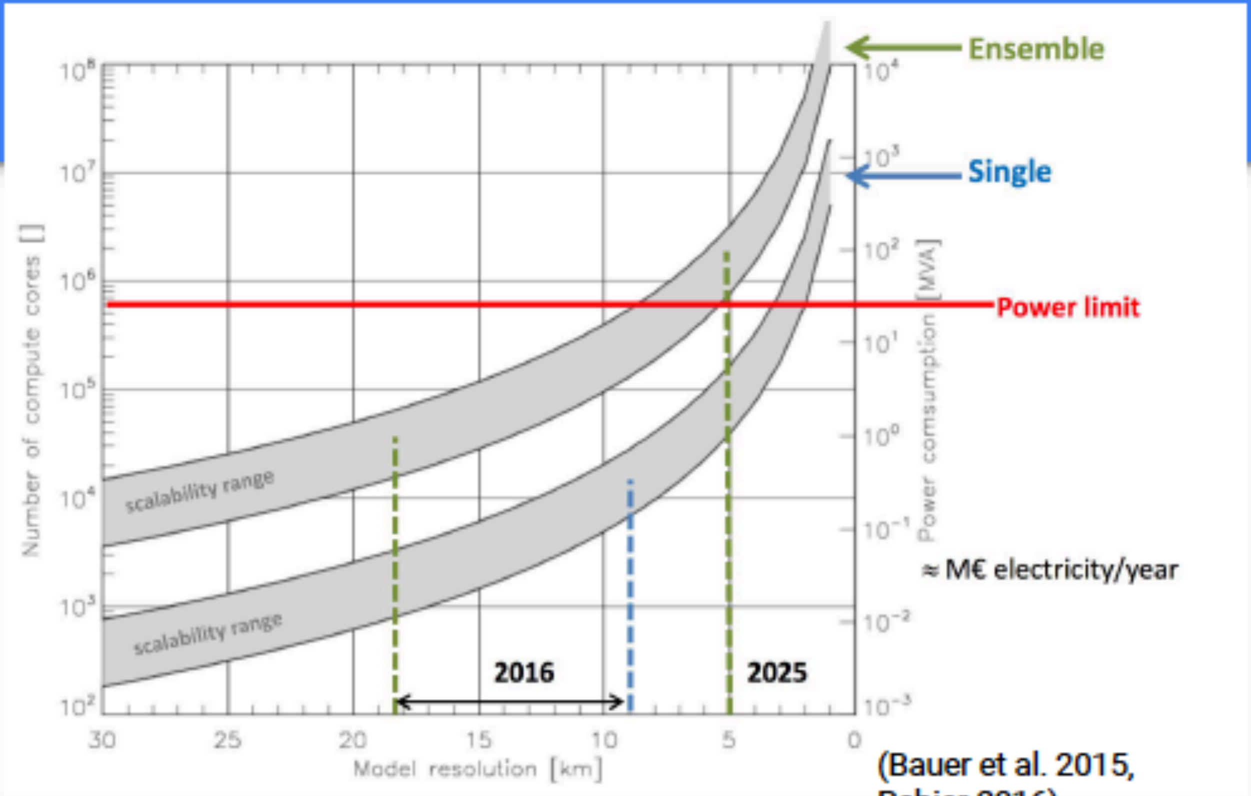
Topic 4 – Computational complexity

The cost of large simulations

Oliver Sutton (University of Reading)

James Stanley Targett (Imperial College)

Energy usage is a serious concern



(Bauer et al. 2015, Rabier 2016)

The energy cost of running a supercomputer for 2 years is more than the cost of purchasing it!

$$\text{Cost} \approx \text{Model} \times \text{Numerical method} \times \text{Resolution} \times \text{Precision}$$

but...

$$\text{Accuracy} \approx \min(\text{Model}, \text{Numerical method}, \text{Resolution}, \text{Precision})$$

$$\text{Cost} \approx \text{Model} \times \text{Numerical method} \times \text{Resolution} \times \text{Precision}$$

but...

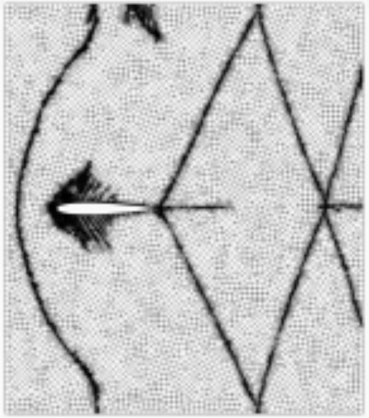
$$\text{Accuracy} \approx \min(\text{Model}, \text{Numerical method}, \text{Resolution}, \text{Precision})$$

Simulation cost optimised by balancing all four

Possible efficiencies

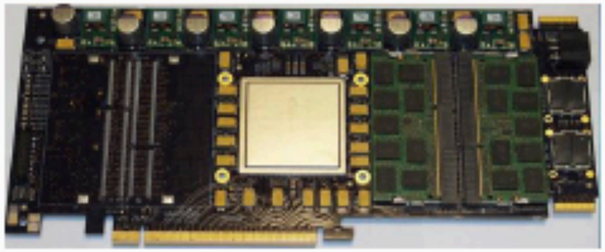
Efficient numerical methods

E.g. Adaptivity



(Pryer et al. 2017)

Low power hardware



Simpler models

Challenges

Validation of numerical methods

Feasibility of complex methods on specialised hardware

Understanding reduced precision

Hierarchy of models

Topic 5 – Observation error correlations

Correlated observation errors

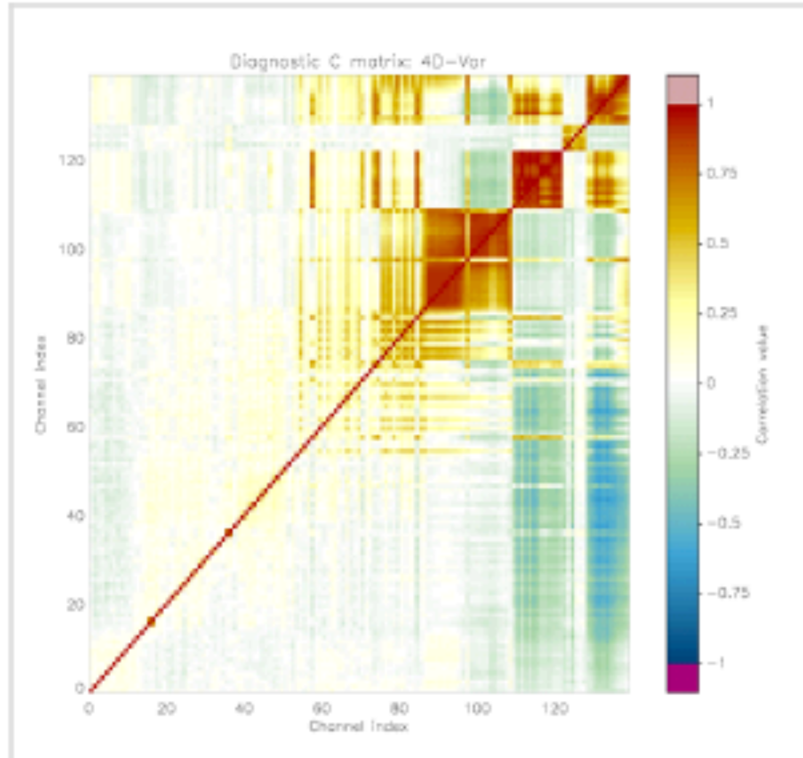
1st September 2017

Problem overview

- High resolution forecasts are key for natural disaster prediction.
- Up to 80% of observations are discarded to try and minimise the effect of correlated observation errors.
- Knowledge of observation error correlations would allow use of more observation data.
- Main causes of correlated errors:
  1. Errors in transformation of indirect variables, e.g. satellites and radar.
  2. Difference in model grid and observation scales.
  3. Artificial correlations induced by errors in the model.

Current state of the art

- The introduction of correlated observation errors is very recent (Weston 2011).
- Correlated observation errors are more computationally expensive, meaning most weather centres used uncorrelated errors until recently.
- The Desroziers diagnostic is used to diagnose observation error correlations. This relies on accurate knowledge of the errors in a corresponding model run.
- Additional mathematical methodologies would increase confidence in the correlations.



Open problems

1. New methods - develop alternative methods of determining observation error correlations.
   - More mathematically rigorous method e.g. from statistical theory.
   - Operationally motivated methods e.g. utilising conventional observations to "constrain" satellite/radar observations.
2. Error attribution - identify and quantify sources of error in models and assess how these introduce observation error correlations.
   - How do we expect correlations to be introduced via a radiative transfer model in a more analytic way?
   - Instrument calibration is a related problem.
3. Temporal correlations - will become increasingly important as spatial/interchannel correlations are taken into account.

Topic 6 – Tipping Points

CLIMATE TIPPING POINTS

“Little things can make a big difference”

At a particular moment in time, a small change can have large long-term consequences for a system.

Tipping element is defined as the trigging process that may lead to a change in base state of a system.

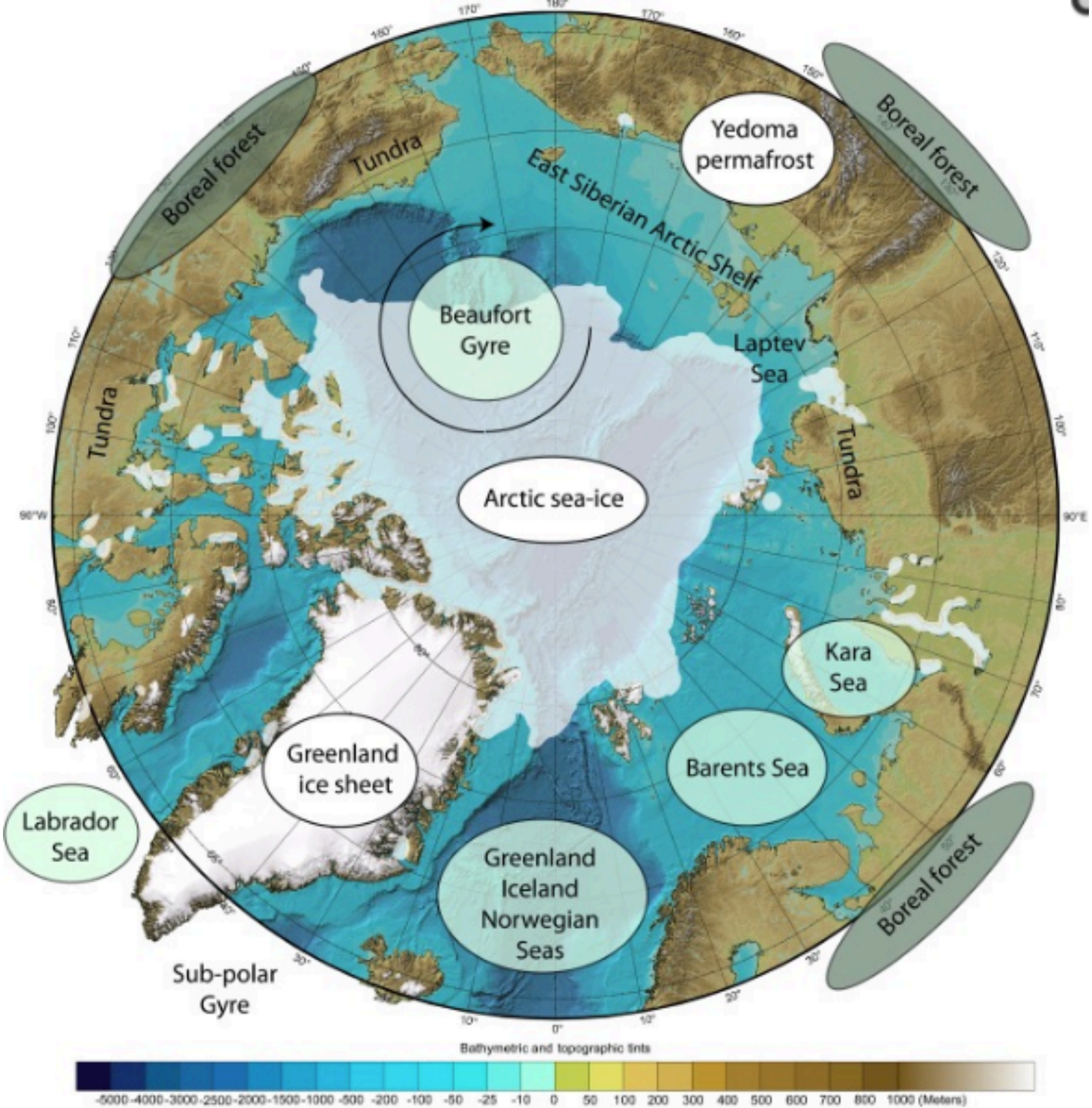
Point of no return X Bifurcation point”

To be effective a tipping point must relay in a system which has some strong positive feedbacks in it’s internal dynamics

CLIMATE TIPPING POINTS

When trying to indetify climate tipping elements, we should look for positive feedback processes.

More precisely, to qualify as tipping element it must be possible to identify a single parameter (P) for which there exist a critical control value ($P_{\mathbf{crit}}$) from which a small perturbation ($\delta P > 0$) leads to a qualitative change in a crucial feature of the system (ΔF) after some observation time ($t > 0$) . Lenon (2012)


Boreal forest
Tundra
East Siberian Arctic Shelf
Yedoma permafrost
Boreal forest
Beaufort Gyre
Laptev Sea
Tundra
Tundra
Arctic sea-ice
Kara Sea
Barents Sea
Greenland ice sheet
Labrador Sea
Greenland Iceland Norwegian Seas
Boreal forest
Sub-polar Gyre
Bathymetric and topographic tints
-5000 -4000 -3000 -2500 -2000 -1500 -1000 -500 -200 -100 -50 -25 -10 0 50 100 200 300 400 500 600 700 800 1000 (Meters)

How to identify those tipping points and tipping elements in a robust manner for climate changes and new climate behaviours, to allow decision makers to make right calls?