

Mexican Collaborations - Projects XPLORE, XIBALBA, and XIB_TCS ^{07/03/2017}

Extended Karst Studies with Innovative Methods in Area of Tulum/Mexico

Aerogeophysics – hydr. Modeling – 3d Laserscanning – Laser Flux Imaging – TCS-Monitoring



Arnulf Schiller



СЕРТИФИКАЦИОННЫЙ МЕДИЦИСКИЙ ЦЕНТР
ИЗДАНИЕ 2014 ГОДА. ВВЕДЕНО В ЭКСПЛУАТАЦИЮ 15.05.2014 ГОДА

History of 10 Years Austrian-Mexican Cooperation in Tulum

07/03/2017

2006: Pilot ground surveys in the Tulum karst system: ERT, EM.

2007: First aerogeophysical survey and ground measurements.

2008: Second aerogeophysical survey and ground measurements.

2008 - 2012: Project Xplore

Goals: Acquisition and advanced processing of geophysical data for input of innovative hydrogeological modeling (UNINE) / advanced imaging of the karst conduit system with AEM-data.

2009: Aerogeophysics near Cancun and Chetumal, Socorro, extended ERT in Tulum.

2010: Large ground geophysical campaign (ERT, GPR, borehole geophysics, set up of GWL logger network, water analysis on site and in laboratory).

2011: High precision GPS GWL survey, retrieval of GWL/halocline loggers, water analysis.

2012: High precision GPS GWL survey with inland tides observation, water analysis.

2012 – 2017: Project Xibalba

Goal: Medium/Small scale acquisition of hydrogeological parameters with innovative Methods (conduit geometry laser scanning, laser flux imaging) directly in the conduits, ERT, extended GWL observation, tracer tests. Refining hydrological model (UNINE).

Starting 2016: Project Xib_TCS: Citizen supported ground water monitoring network.

Partners



Geological Survey of Austria



Amigos de Sian Ka'an
Gonzalo Merediz Alonso



Technical University of Denmark



Philippe Renard



Steffen Birk



Marco Philipponi



Wolfgang Kinzelbach



Secretaría de Marina
Armada de México



Sam Meacham



Robbie Schmittner



Mario Rebolledo-Vieyra
Arnulf Schiller, Geological Survey of Austria



Bil Phillips



4

Project Funding



The Nature Conservancy, Unesco (AEM Surveys Tulum 2008/2009)



Austrian Science Fund (projects HIRISK, Xplore, Xibalba, Xib_TCS)



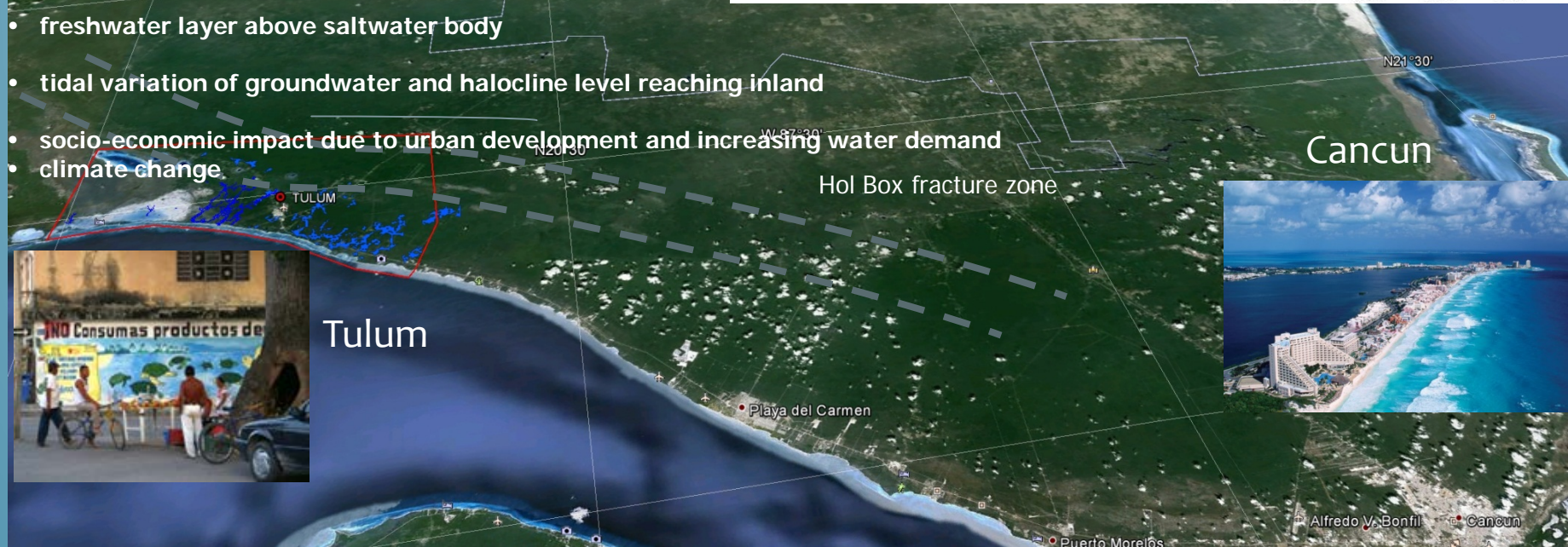
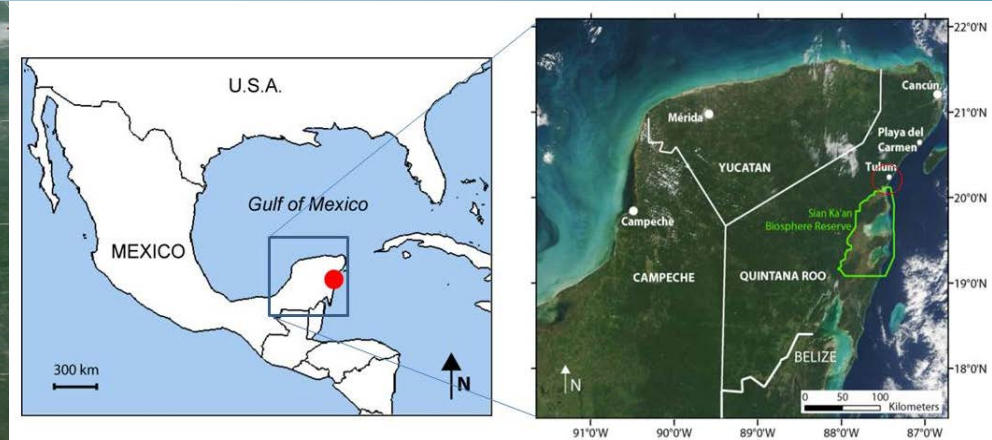
Austrian Academy of Sciences (programme 'Man and Biosphere')



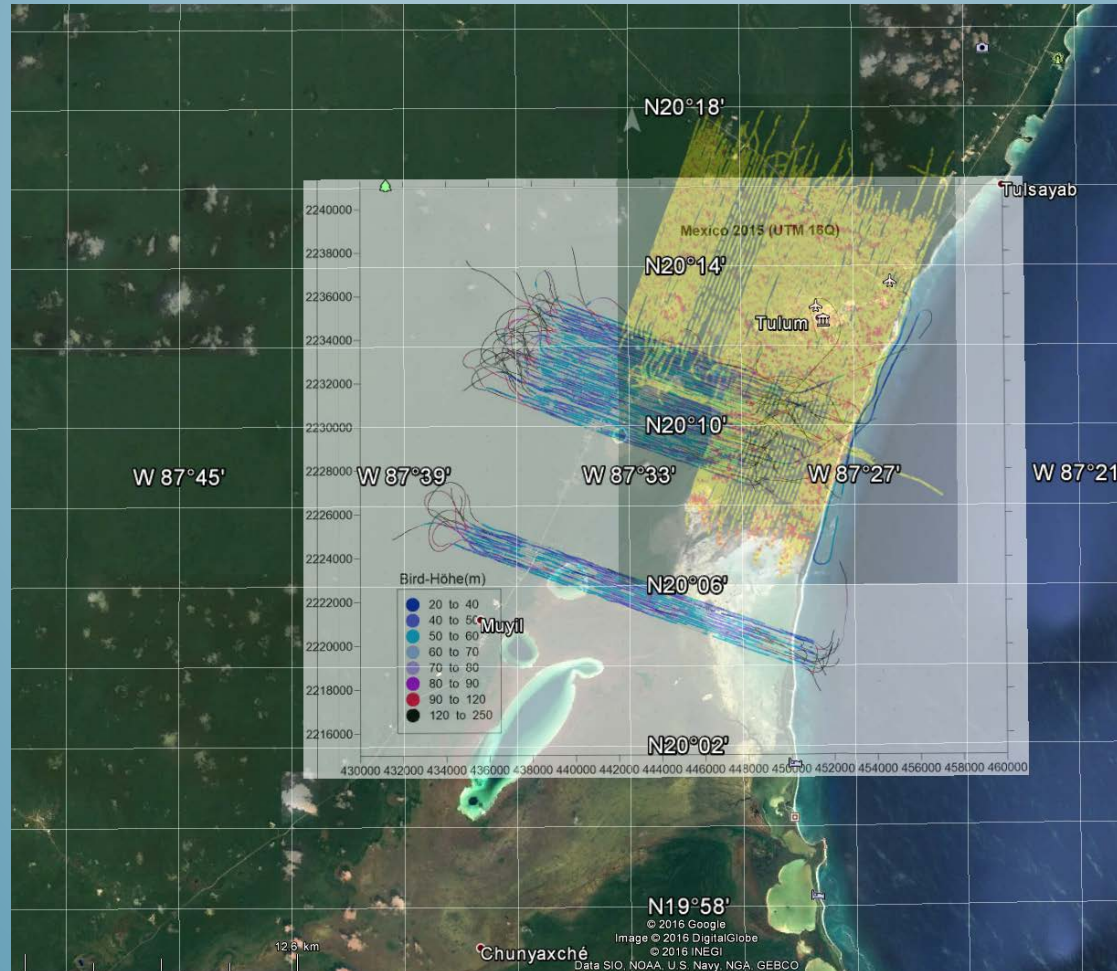
Swiss Science Fund (project Xibalba)

The Survey Area – Tulum Karst Plain

- huge and difficult accessible coastal karst plain covered with forests, mangroves and lagoons
- variably consolidated limestones several 1000 metres thick.
- thin soil cover – limestone exposed at the surface
- flat topography (0 - ~50 m above mean sea level)
- known conduits/caves explored by cave divers
- freshwater layer above saltwater body
- tidal variation of groundwater and halocline level reaching inland
- socio-economic impact due to urban development and increasing water demand
- climate change



AEM Surveys Tulum 2007, 2008 and 2015: approx. 250 km²



Project XPLORE – Problem Statement and Methodology

- Can **AEM** map the underground conduit system?
- Can a Karst water regime be described by **combining aerogeophysical and hydrogeological** methods?

Methodology:

Pilot surveys, simulation of measurement situation – estimation of expected measurement signal

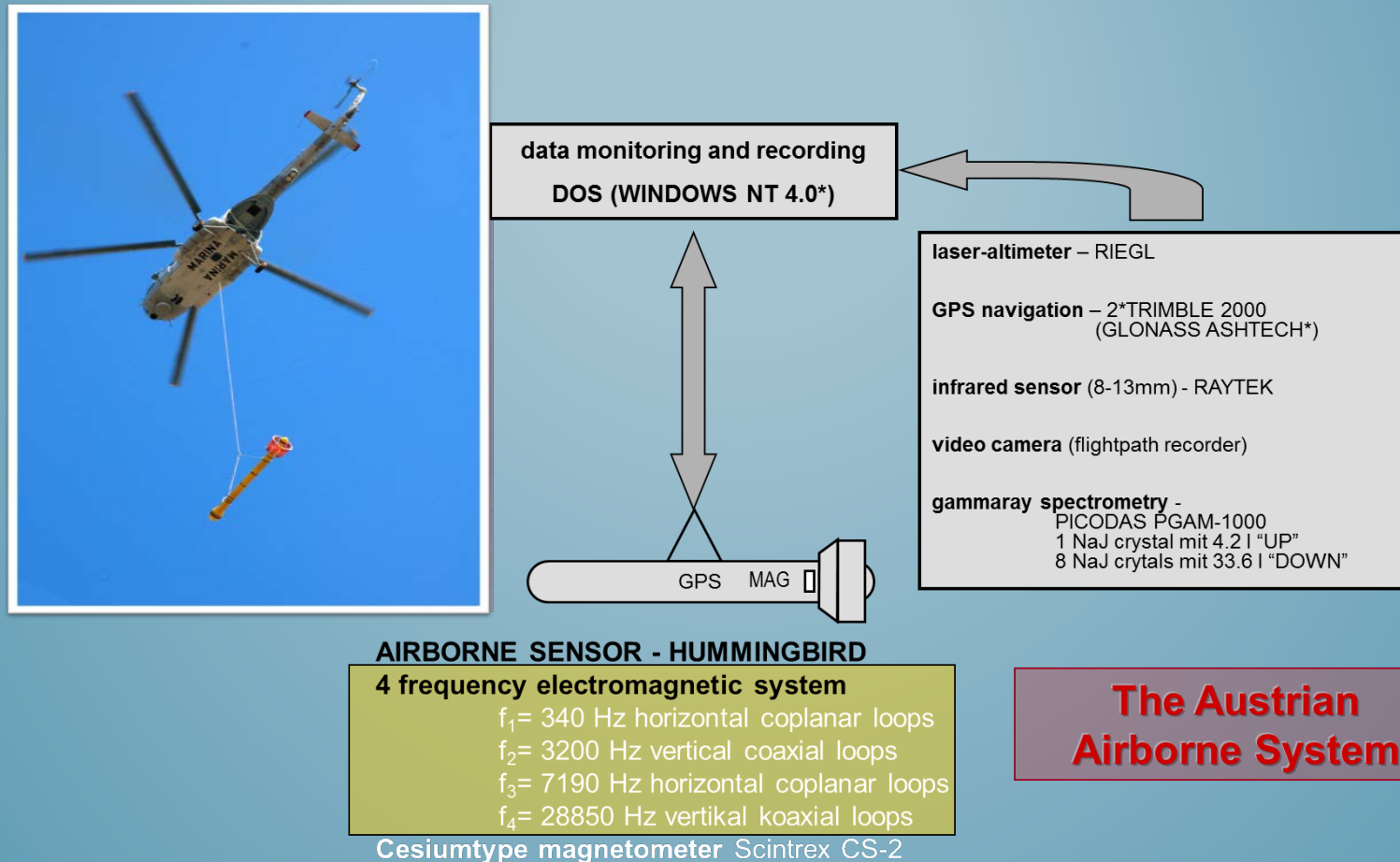
AEM-Survey → **electrical conductivity** in the subsurface (through 1D-inversion)

El. Conductivity → lateral and vertical distribution of **hydrogeological relevant structures** (due to distribution of porosity, water saturation, ion concentration, permeability, GWL, halocline) – Map of potential conduits.

Structural information from AEM and under water cave surveys → **Groundwater model**

Calibration of AEM-measurements and groundwater model by ground survey data (ERT, bore hole geophysics, piezometry, GPR)

The measurement platform



Helicopter provided by the Mexican Marina (MilMi - 8)





07/03/2017



load specialist

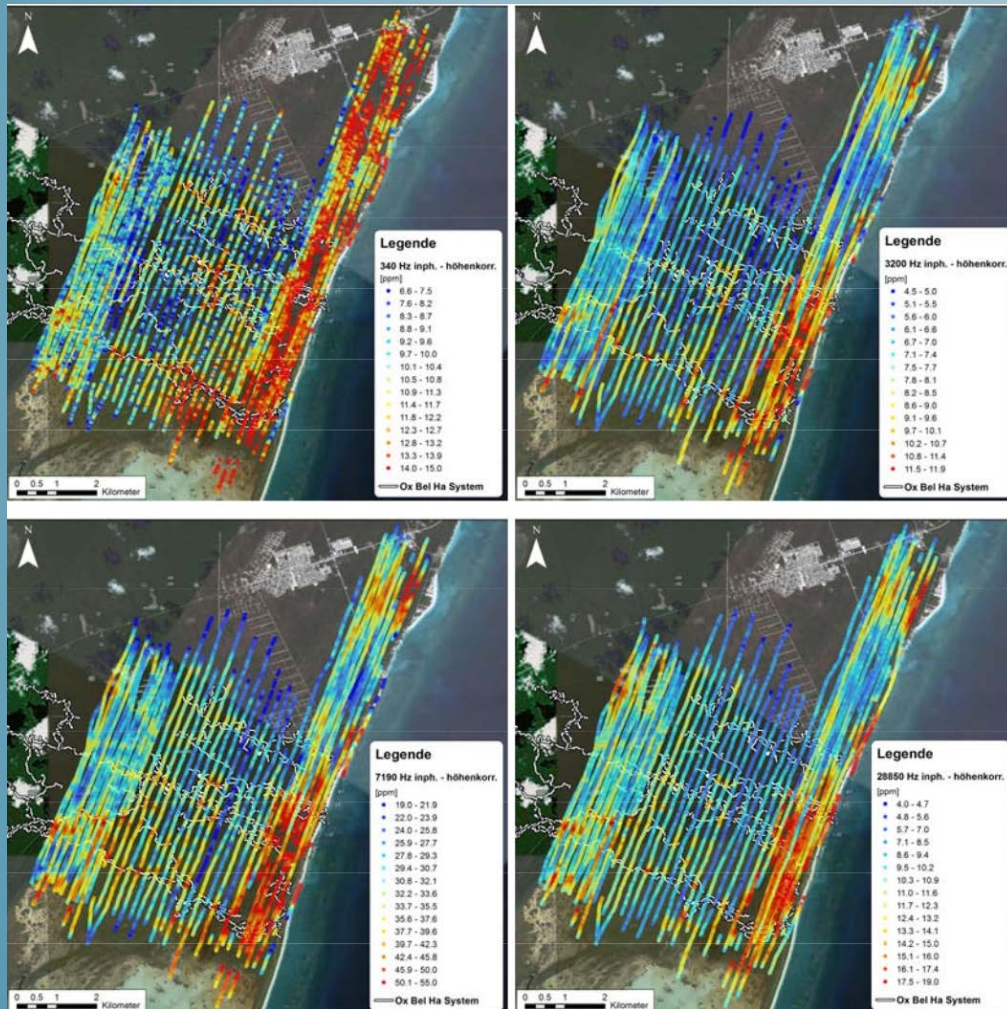
Bird 30 m below the helicopter



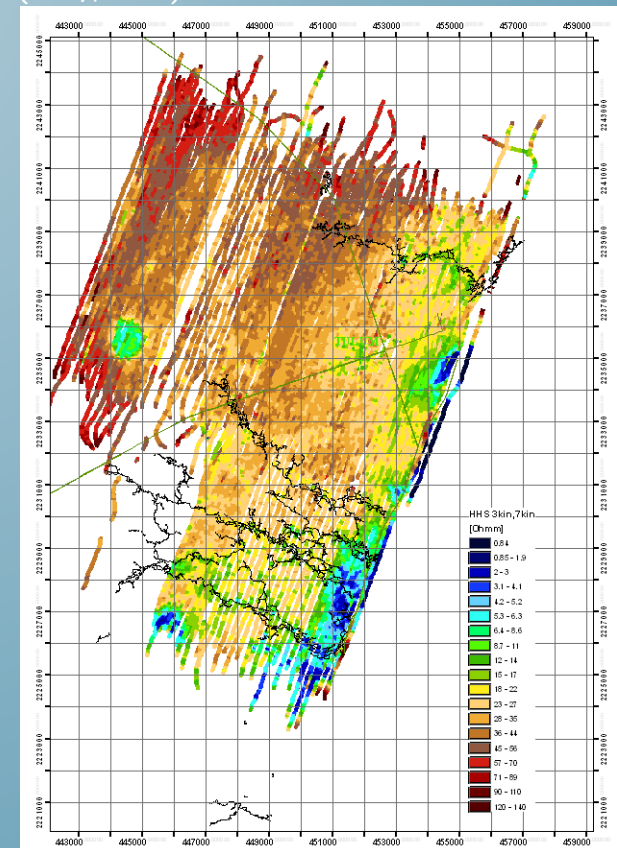
The 2007/2008 AEM surveys –first results

known caves are detected – some indication of further conduits

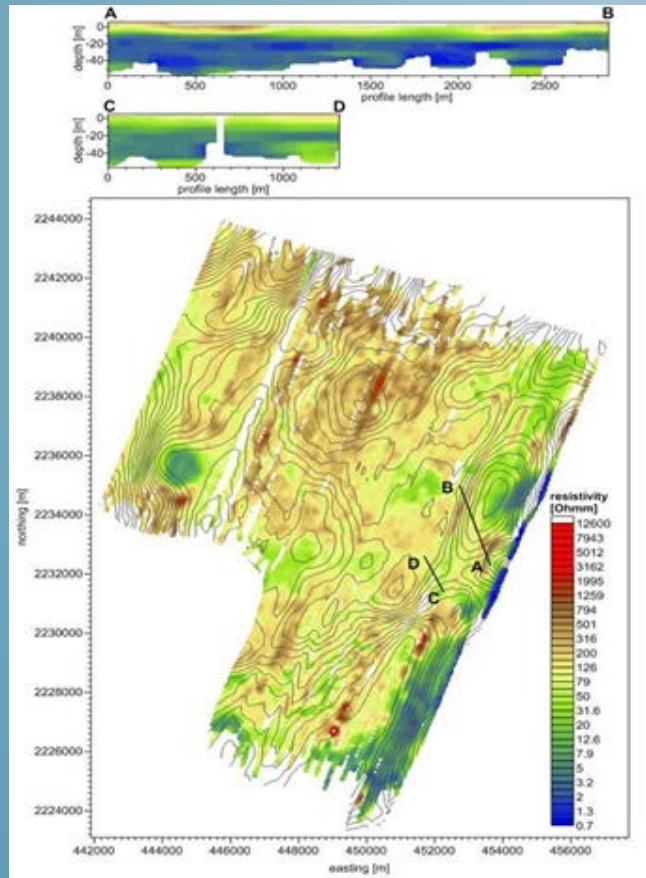
Edited and height reduced raw signal (ppm) of all inphase components (2007)



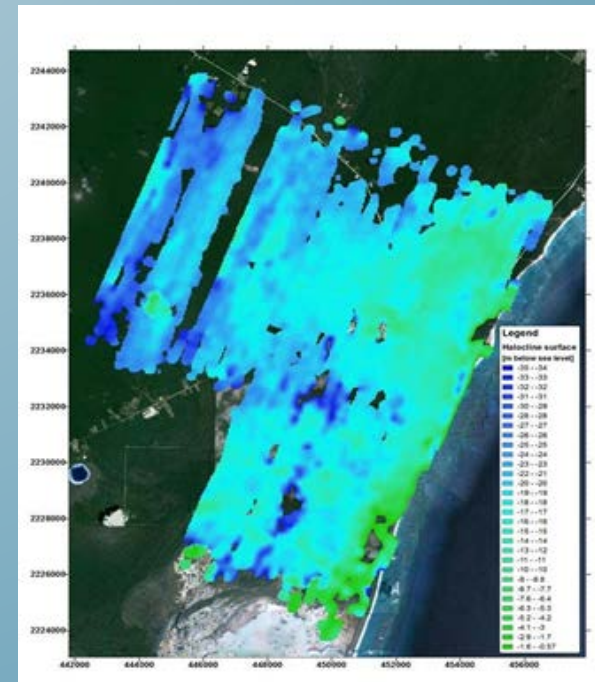
Halfspace inversion from 3k_in, 7k_in – phases (2007/2008)



AEM-data inversion
 surface layer and two sections
 (software: UBC EM1DFM)



Estimated topography
 of halocline
 (Interpreted as
 4 S/m – isosurface)



Getting out more information - adapting AEM processing for enhancing signals of possible conduits

- 1) System drift analysis (HIRISK)
- 2) Automatic drift correction based upon findings/developments of FWF project HIRISK.
- 3) Estimation and correction of residual drift by analysis of vertical field gradient.
- 4) Destripping (type of micro-levelling).
- 6) Advanced reduction of active interferences (median/phase filtering, in development)

2007/2008 f3_in , reduced to 40 meters above ground, meanfree.



System drift analysis

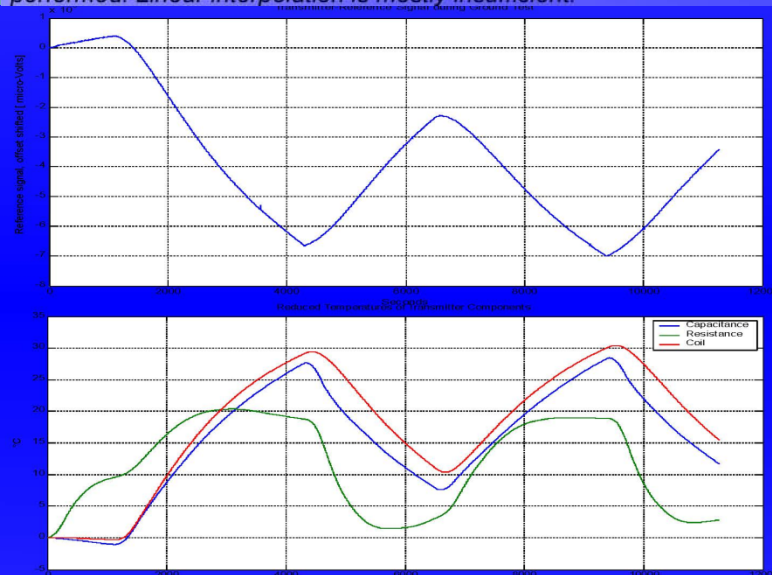
(FWF - project HIRISK)

The Problem

The system is (as any comparable system) generating non linear drifting of in/out- phase components due to following sources:

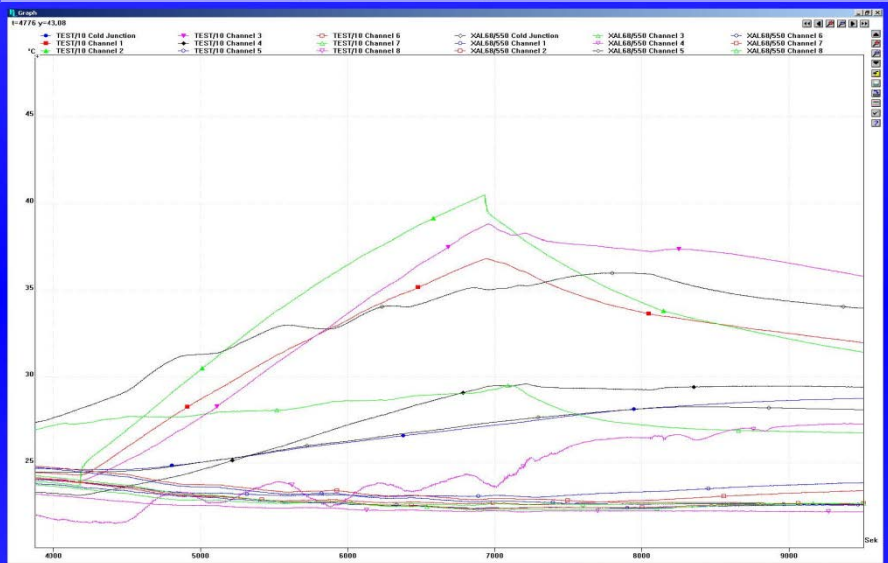
- D/A conversion of synthetic signal
- Transmitter amplifier
- Transmitter circuits
- Suboptimum impedance matching
- Variable Tx/Rx - coil geometry
- Receiver circuits
- Suboptimum Rx/Bx primary field compensation
- Receiver pre-amplifier
- Receiver A/D conversion
- Parasitic secondary fields originating from hardware, wiring etc.

All these sources are highly temperature sensitive. As temperature (environmental or self generated) changes continuously with time, nulling, phasing and Q-coil calibration is valid only for the time performed! Linear interpolation is mostly insufficient.



Identified main drift sources:

- Temperature induced changes in Tx/Rx circuit parameters => detuning, suboptimal impedance matching, suboptimal bucking compensation, temperature sensitivity of analogous hardware (anti-aliasing-filter, amplifier)
- Residual drift originating from system immanent secondary fields (hardware, wiring) => difficult to simulate accurately.
- Modeling of contributions by least squares fitting which attempts to solve a system of linear equations $A*x=b$ for x if A is consistent, otherwise it attempts to solve the least squares solution x that minimizes $\text{norm}(b - A*x)$. In this case 'b' represents the drifting data, 'A' the temperature dependent transfer-functions calculated with measured component temperature and x represents the contributions as well as the higher order temperature co-efficients.

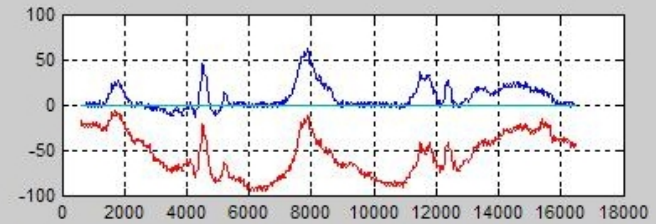
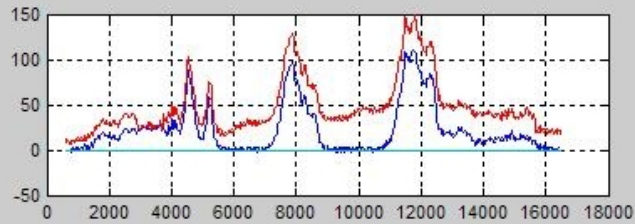


Automatic signal drift correction by means of transmitter drift correction and drift estimation (result: blue line)

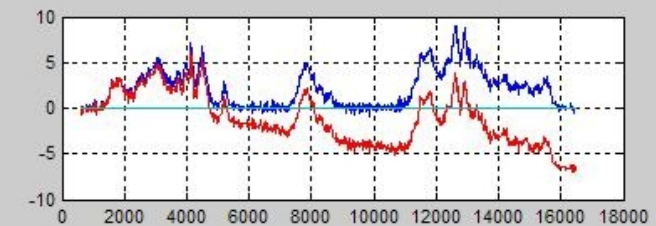
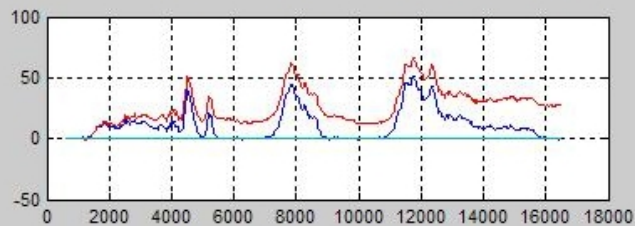
in-phase (ppm)

quadrature (ppm)

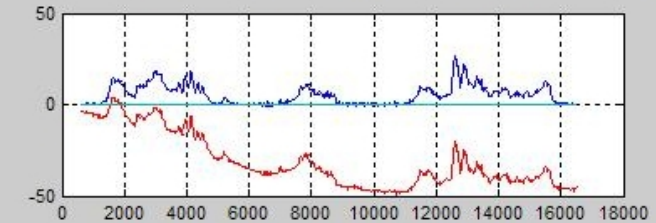
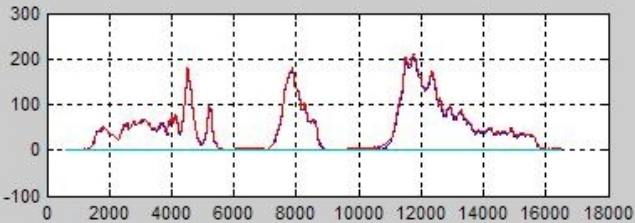
340 Hz



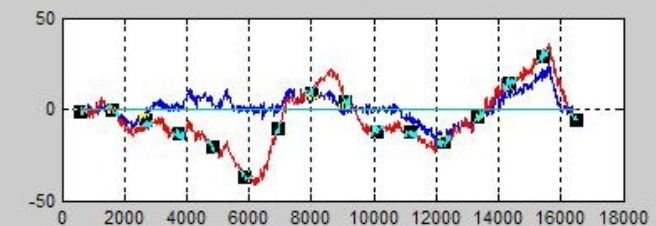
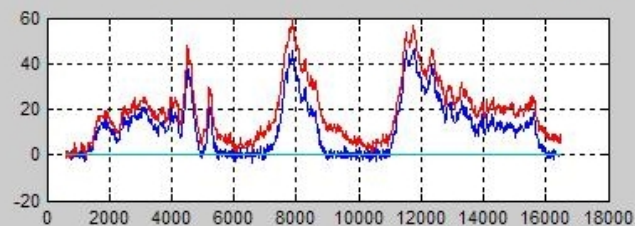
3200 Hz



7190 Hz



2850 Hz



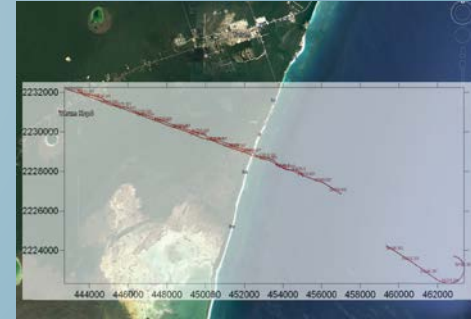
Residual system drift estimation by analysis of signal/height correlation

Extrapolation of signal to $h \rightarrow \infty$ (synthetic nulling during measurement) by fitting a model to data within gliding window. Controlled by quality criterion (standard deviation of fit). Works best above more homogenous layering .

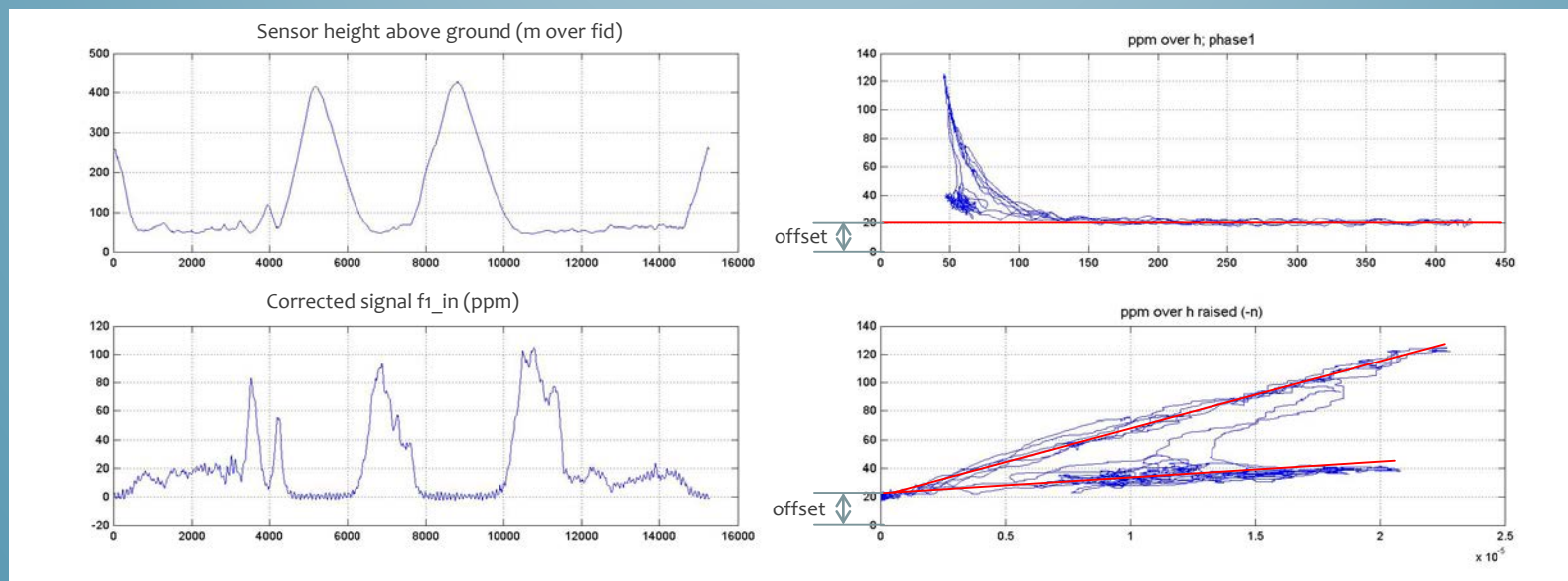
$$s = q \times h^{-n} + d$$

$$s = q \times (h + t)^{-n} + d$$

s ... signal
 q ... source strength
 h ... laser sensor height
 n ... decay exponent (3)
 d ... drift offset



Line YUK003, 2008-survey

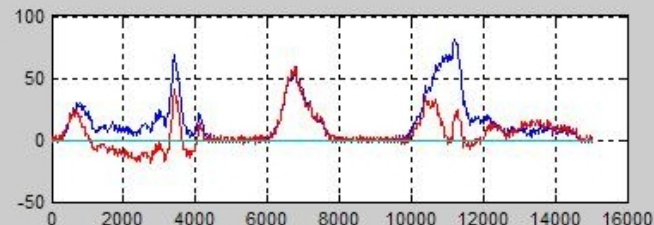
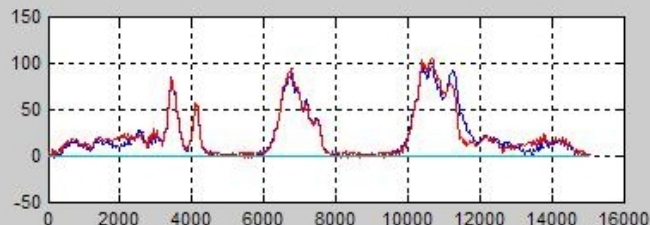


Residual signal offset correction due to signal / altitude relation (result: blue line)

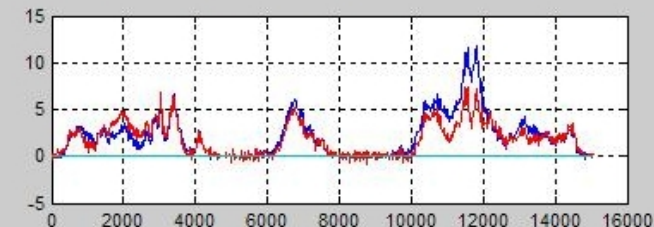
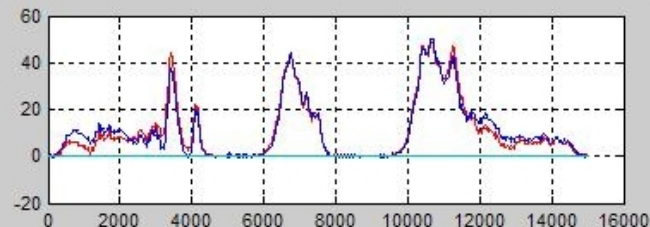
in phase (ppm)

quadrature (ppm)

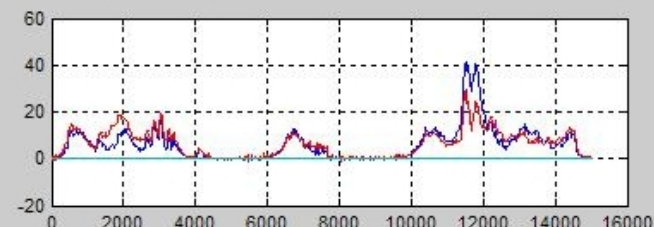
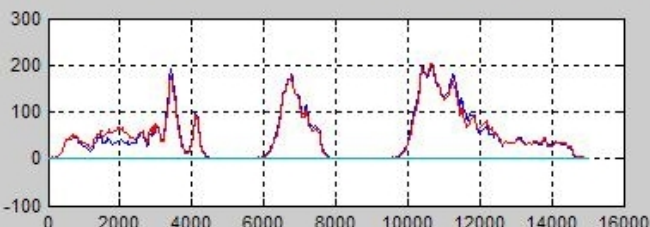
340 Hz



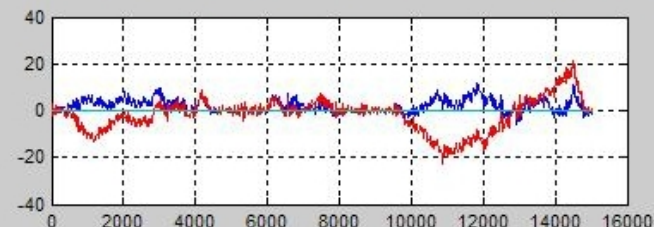
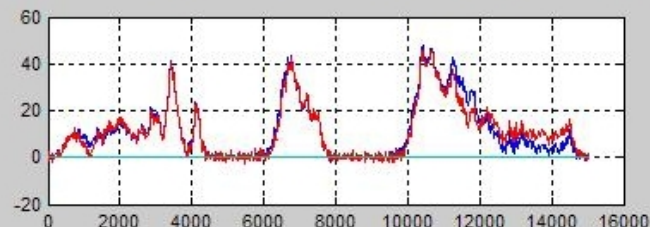
3200 Hz



7190 Hz

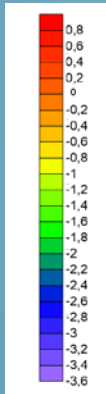


28850 Hz

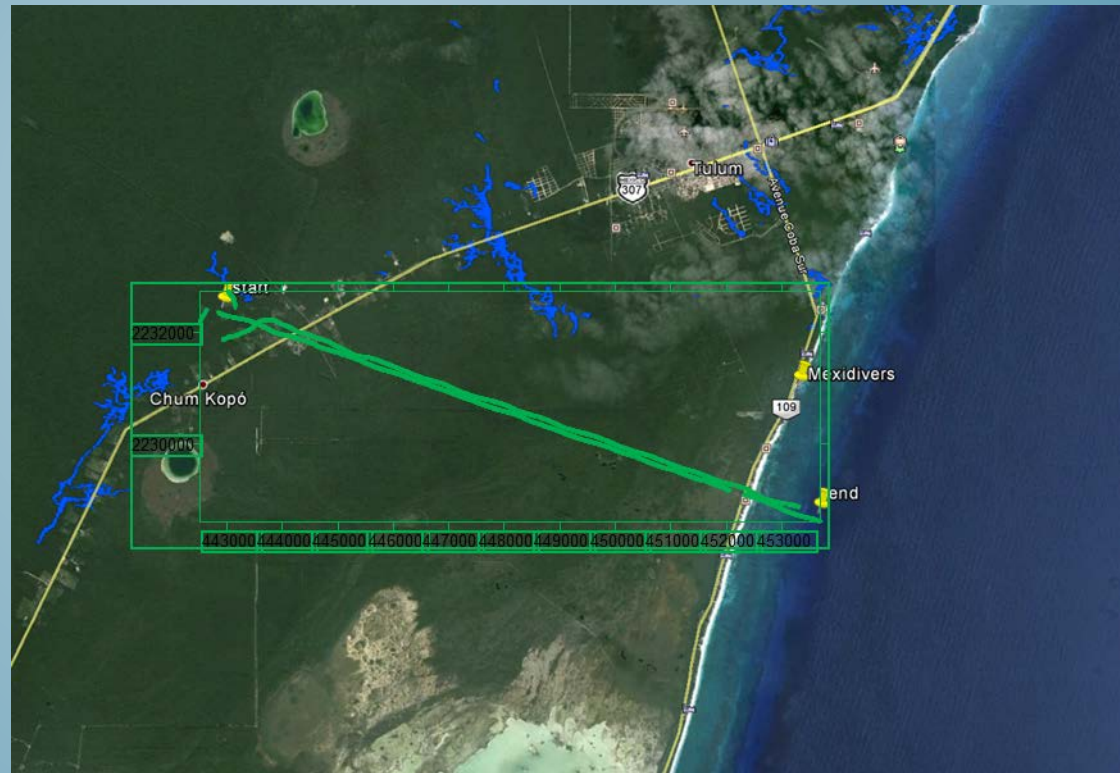


Sections beneath flight lines:

Detection of fresh water layer, mixture zone and salt water body



Electrical Conductivity Log₁₀[S/m]



Line YUK001, 2008-survey

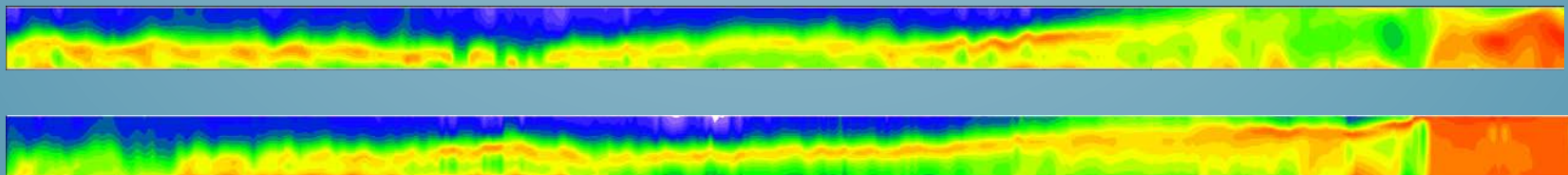
Fresh water layer (blue)

~ 10 km

Low wet land

reef

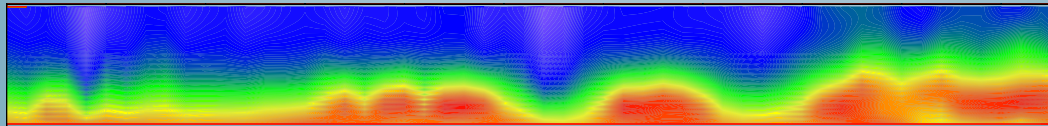
50 m depth



Salt water body (yellow-red)

Where are the caves? – background reduction of strong salt water response in line-inversion results.

YUL054_detail



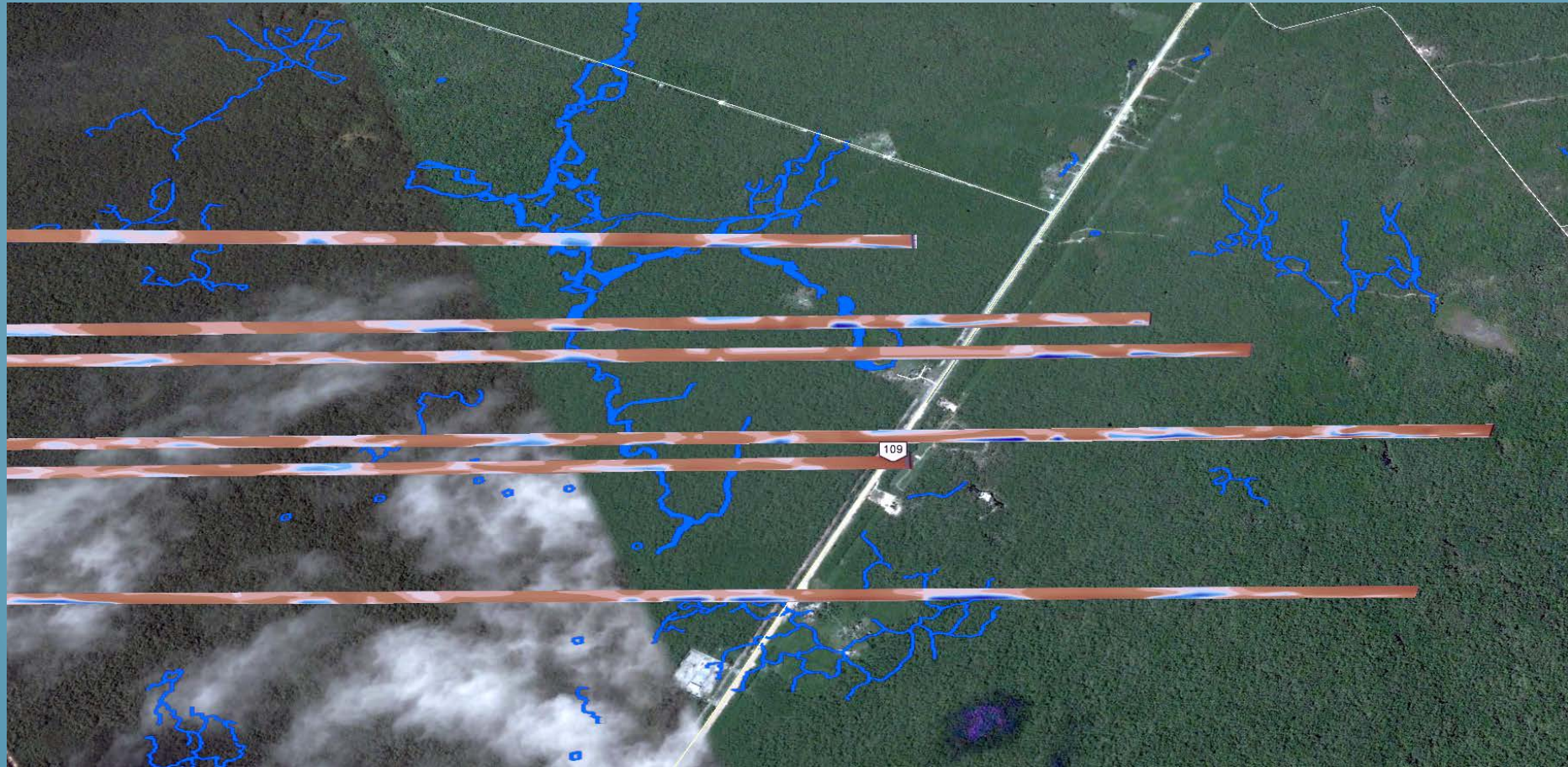
minus

$\log_{10}[\text{s/m}]$

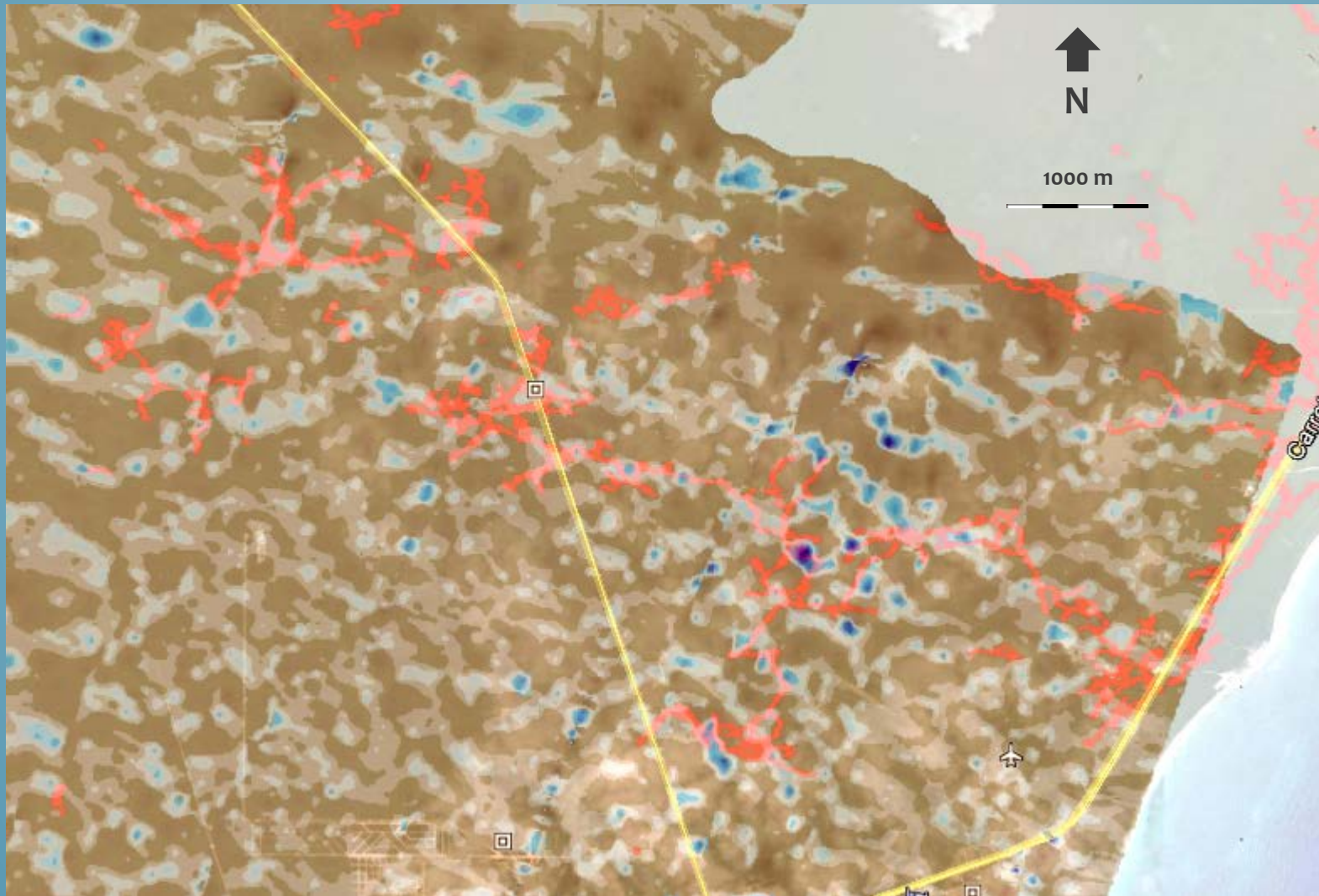
=

L1

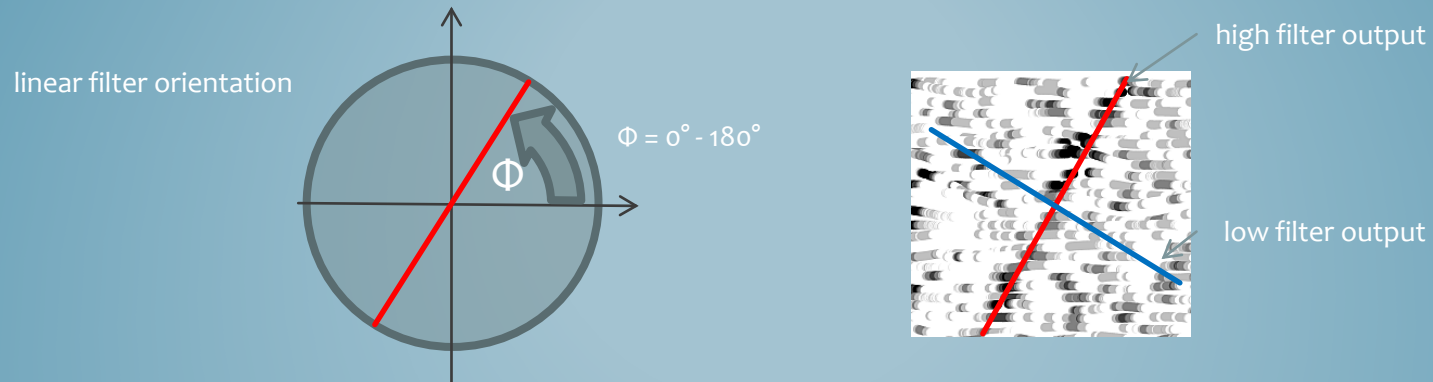
Background reduced sections crossing surveyed cave system



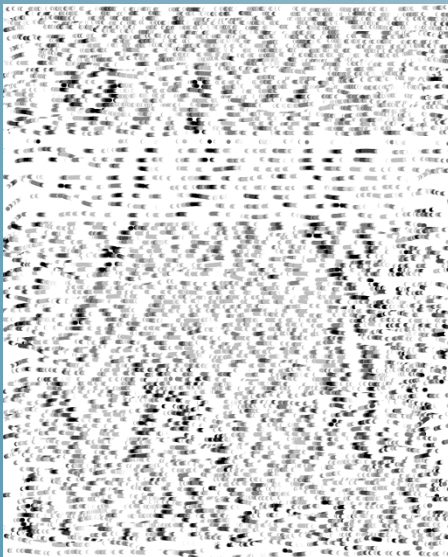
Background reduction– 19.5 metres depth layer - detail



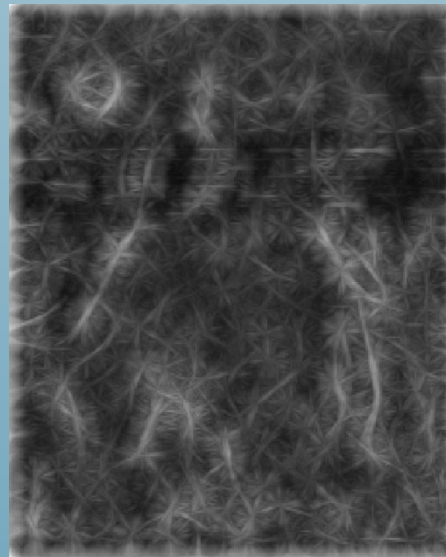
Advanced AEM processing – enhancement of linear structures



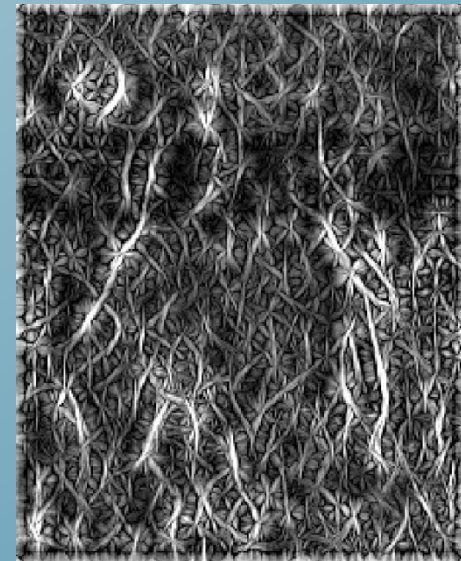
Height reduced and
mean free ppm-signal
(f3_in, part of 2008-survey)



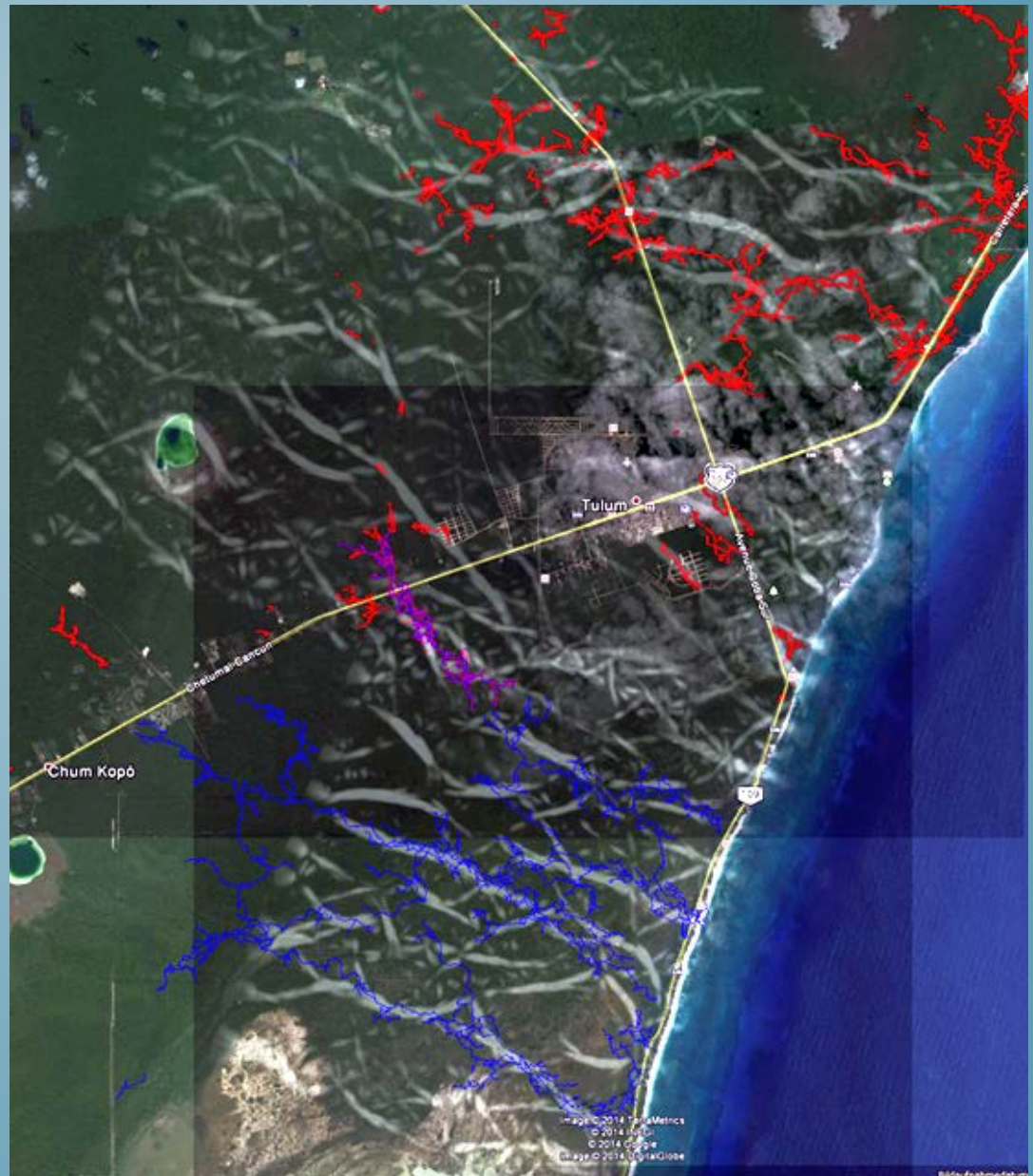
Linear structures enhanced



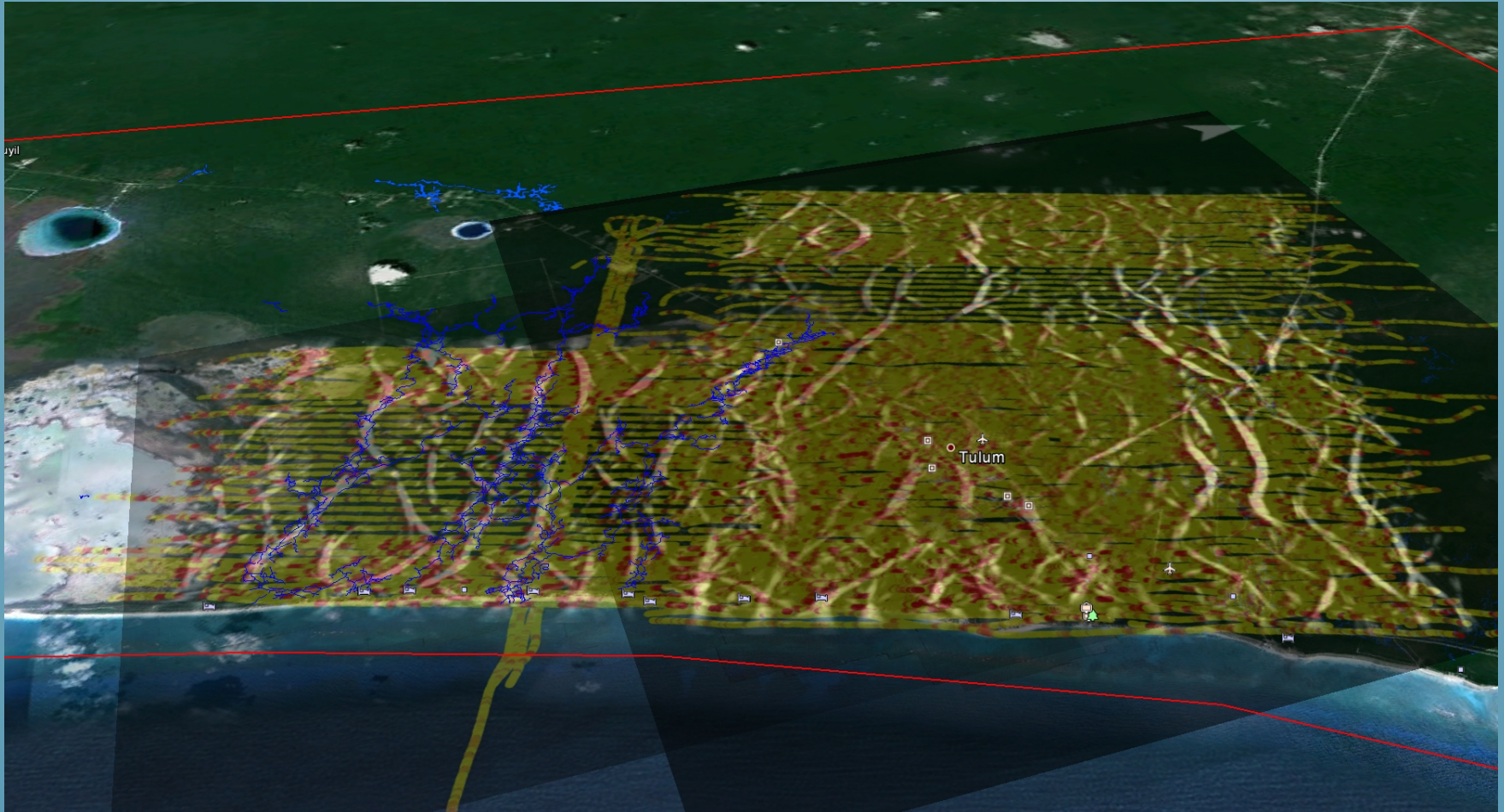
edge filtered



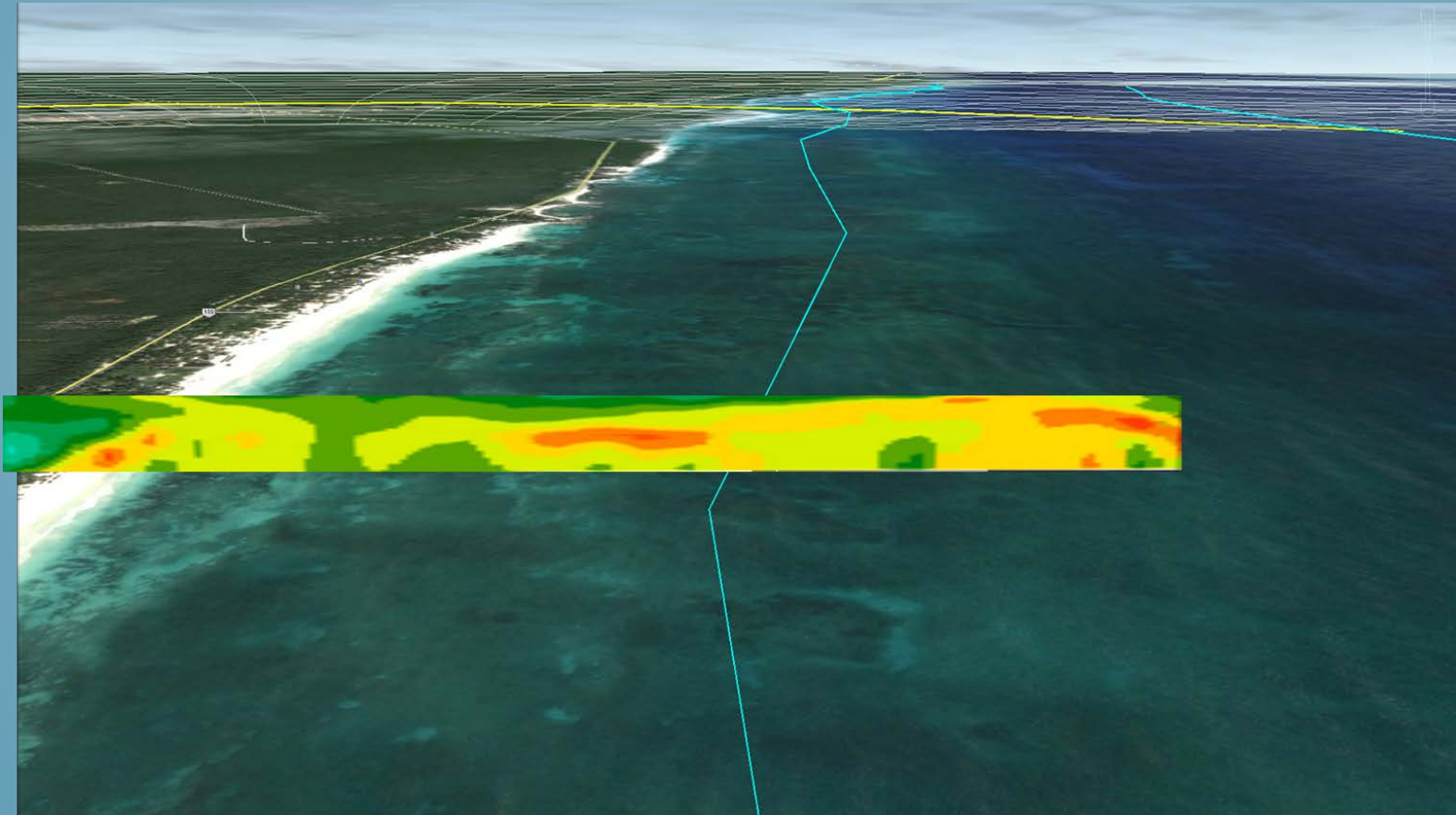
Map of enhanced linear structures compared with surveyed caves



Results: Overview of conduit network (from 2007 and 2008 AEM data)

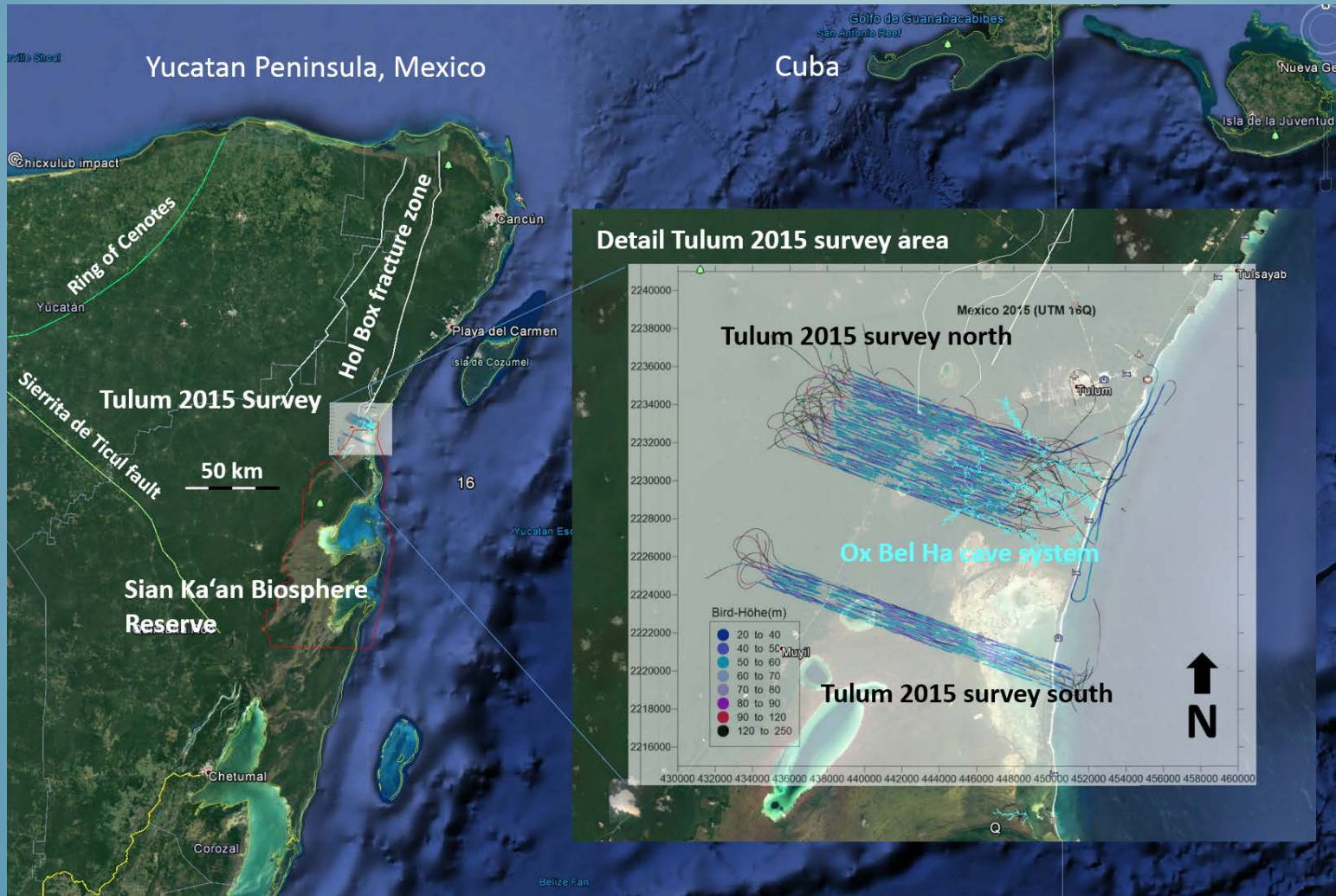


Inversion line YUK001 – detailed section of reef structure

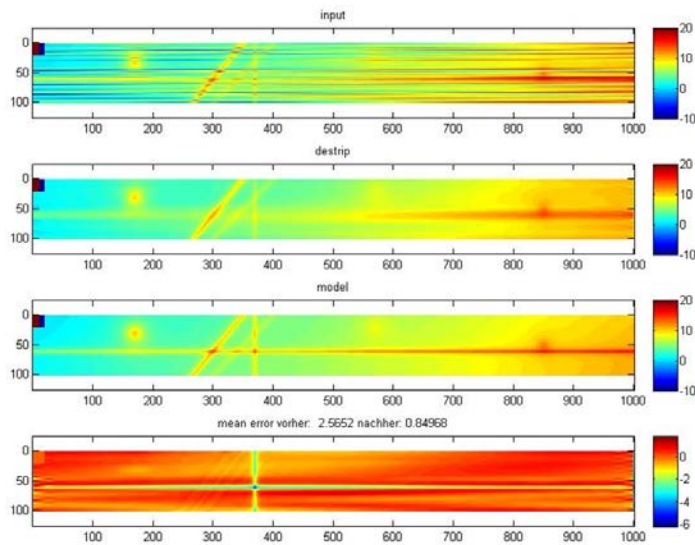




Tulum 2015 AEM-Survey



Test of destripping scheme



Top: synthetic test.

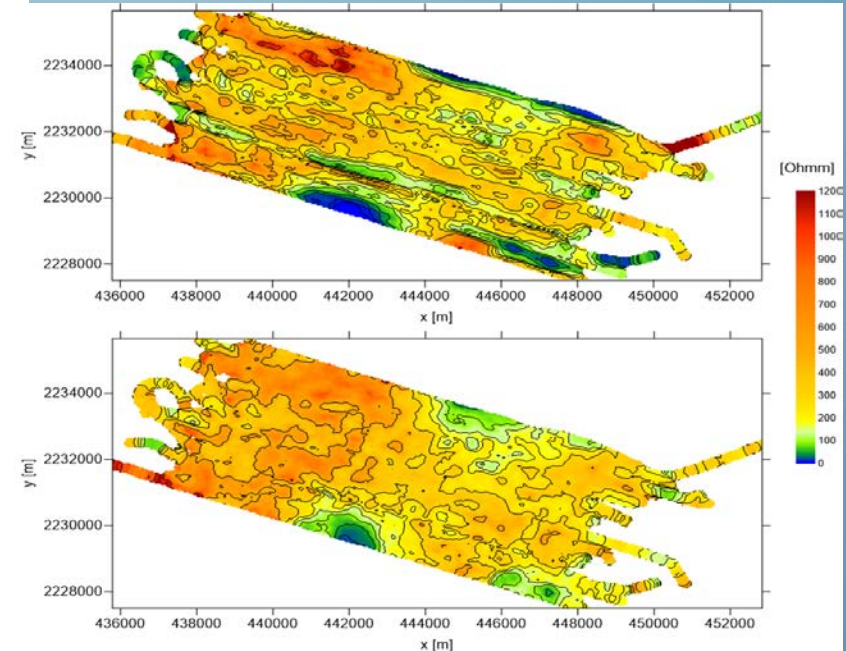
Right: AEM 2015 – north part.
 Inversion result of upper layer (0-3 m).
 top: inversion with residual drift.
 bottom: inversion with destripped ppm
 data input.

Strips caused by residual signal drift
 - spatially uncorrelated normal to flight lines.

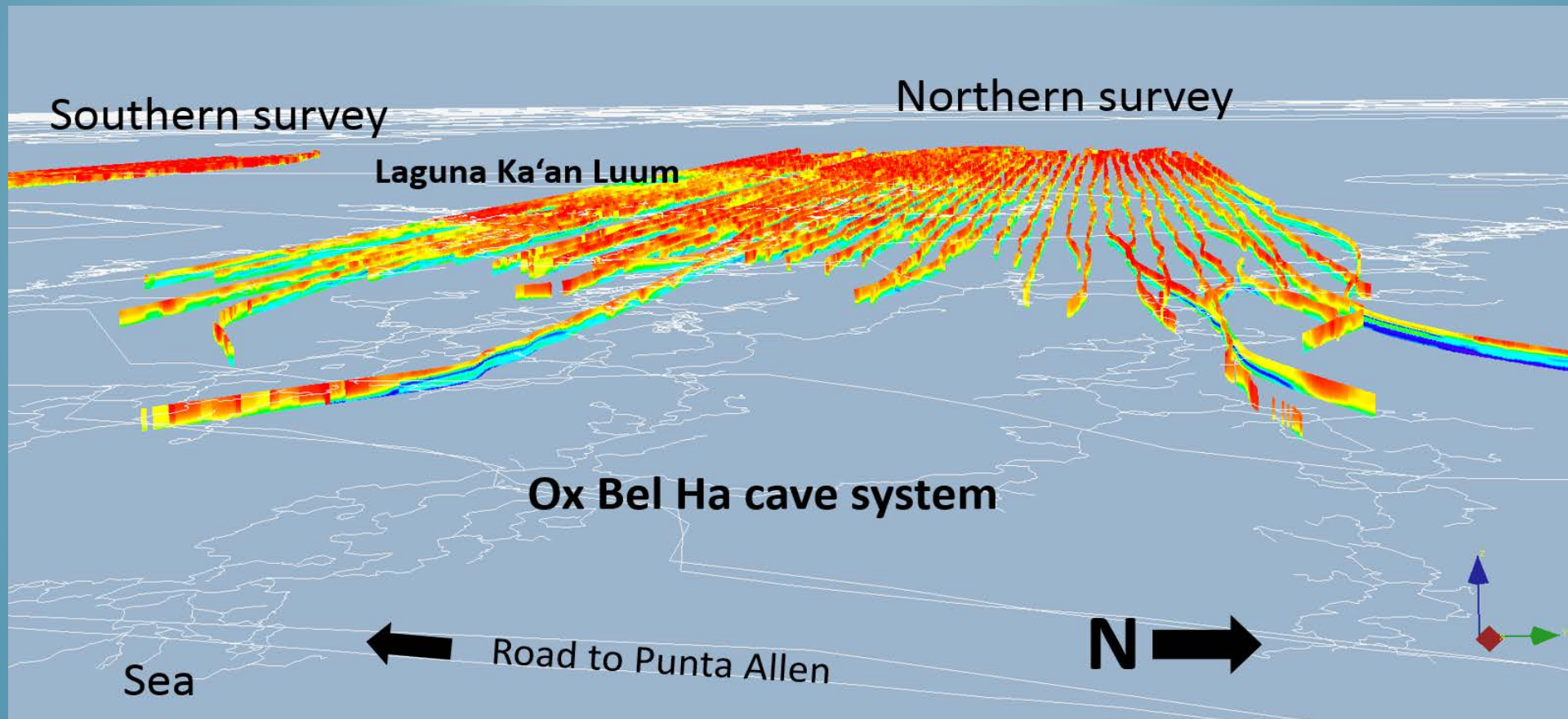
Estimation of spatial frequency content
 of system drift – low pass filtering

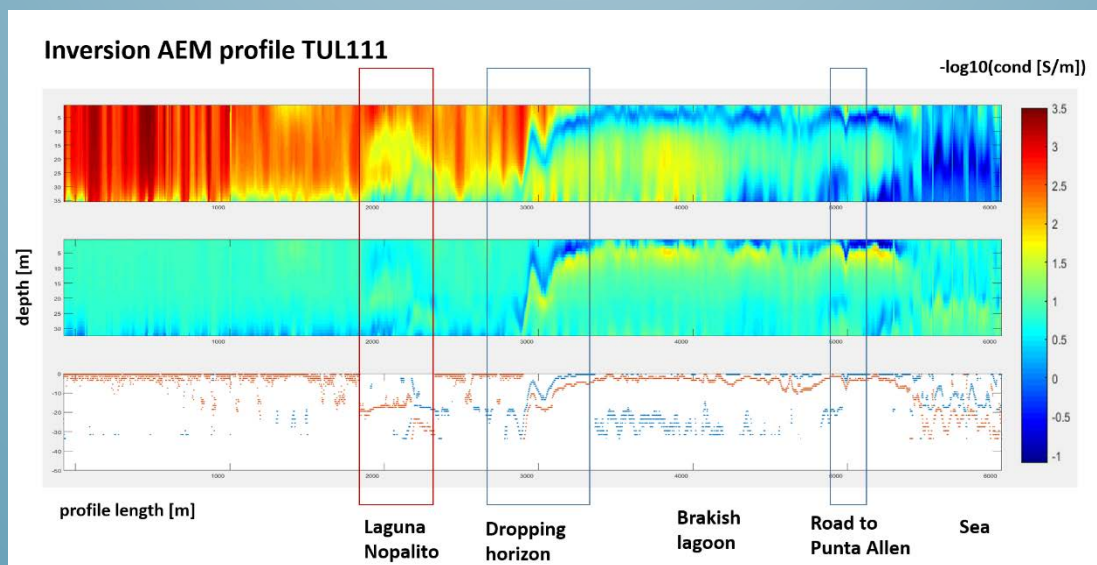
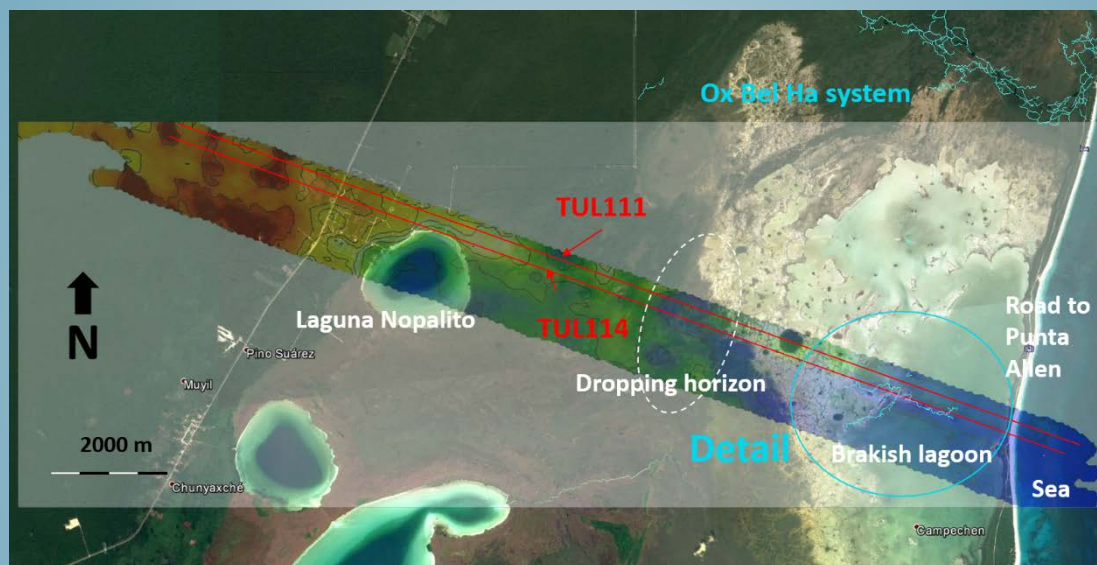
Iterative 3 point balancing.

Minimizing variability normal to lines by preserving
 anomalies along lines.

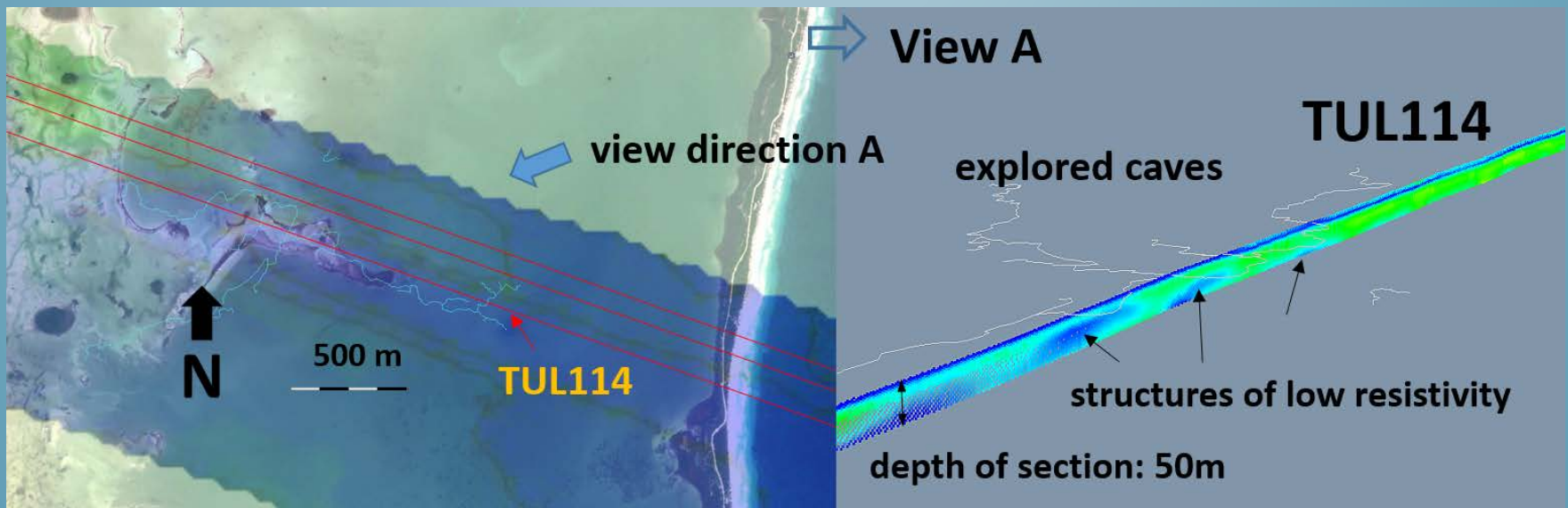


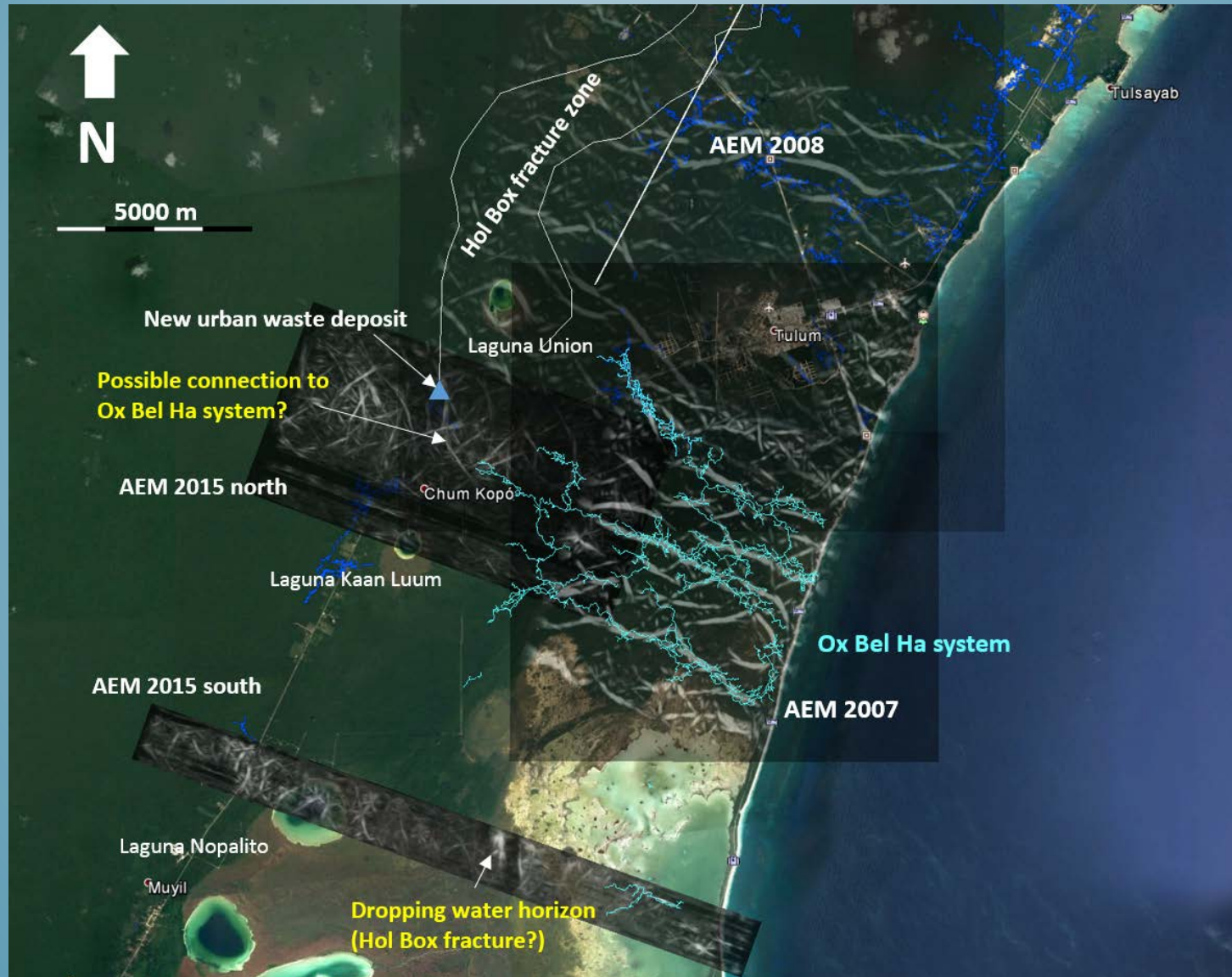
2015 AEM-survey inversion in 3d-representation





Detail of line TUL114. Right: perspective view to section cutting known caves





Conclusion of AEM survey in Tulum Karst:

- Halocline level is well resolved.
- GWL is not clearly resolved in karst (capillary effects). Interpretation with conductivity isosurface problematical (varying porosity).
- Distribution of electrical conductivity derived from AEM as XYZ-volume data correlates to surveyed caves and yields picture of potential karst conduit distribution - lateral and in depth.
- Lateral resolution approx. 50-100m (spacing dependent), maximum vertical resolution 2 m, maximum penetration depth approx. 50 metres in the case of salt water saturated limestone.
- Statistical analysis of distribution of Karst structures enables numerical stochastic simulation/generation of Karst network (Center for Geohydrology and Geothermics, University of Neuchatel).
- AEM plus adapted data processing can deliver important 3d-information about difficult accessible Karst systems in short time.

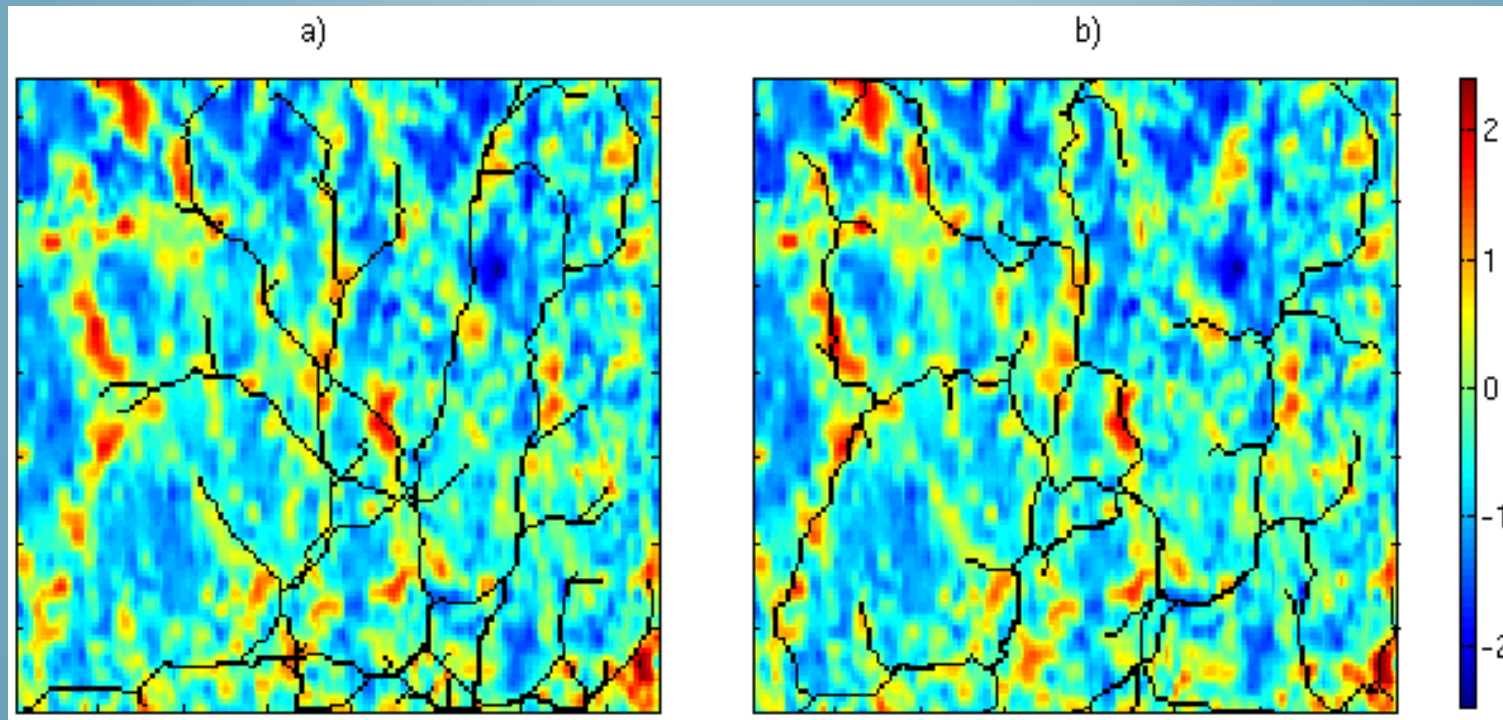
Hydrological modeling – Karst simulator

Stochastic Modelling Group (Philippe Renard), Center for Hydrogeology and Geothermics, University of Neuchatel, Switzerland.

07/03/2017



Realisations of conduit nets governed by AEM and cave survey data.

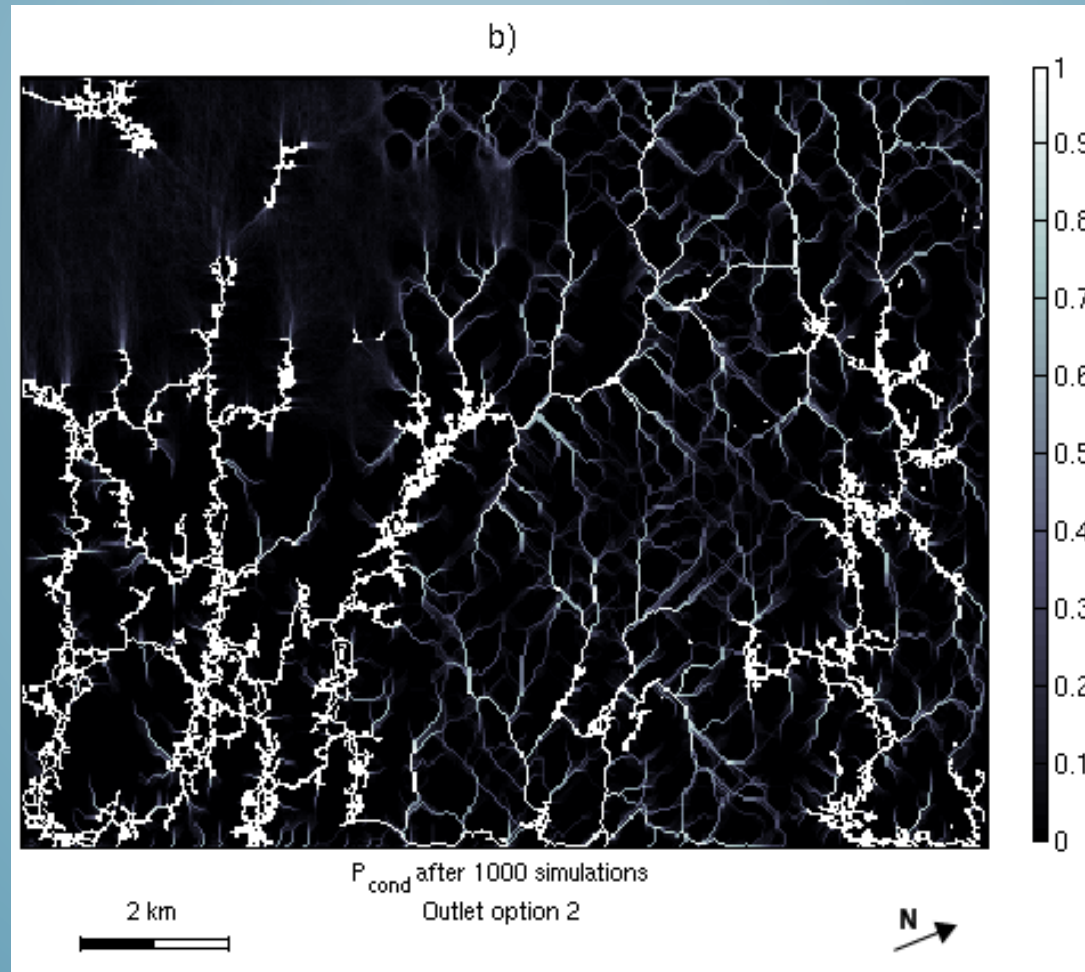


Weak weighting of AEM data

Strong weighting of AEM data

Plot from: C Vuilleumier et al. A method for the stochastic modeling of karstic systems accounting for geophysical data: an example of application in the region of Tulum, Yucatan Peninsula (Mexico), Hydrogeology Journal 21 (3)

Hydrological modeling – conduit probability map



Plot from: C Vuilleumier et al. A method for the stochastic modeling of karstic systems accounting for geophysical data: an example of application in the region of Tulum, Yucatan Peninsula (Mexico), Hydrogeology Journal 21 (3)

Hydrological modeling – simulation results

(P. Renard, C. Vuilleumeier, G. Kaeser, University of Neuchatel)

07/03/2017

Simulated flow velocities through conduits: 0.63-0.93 m/s.

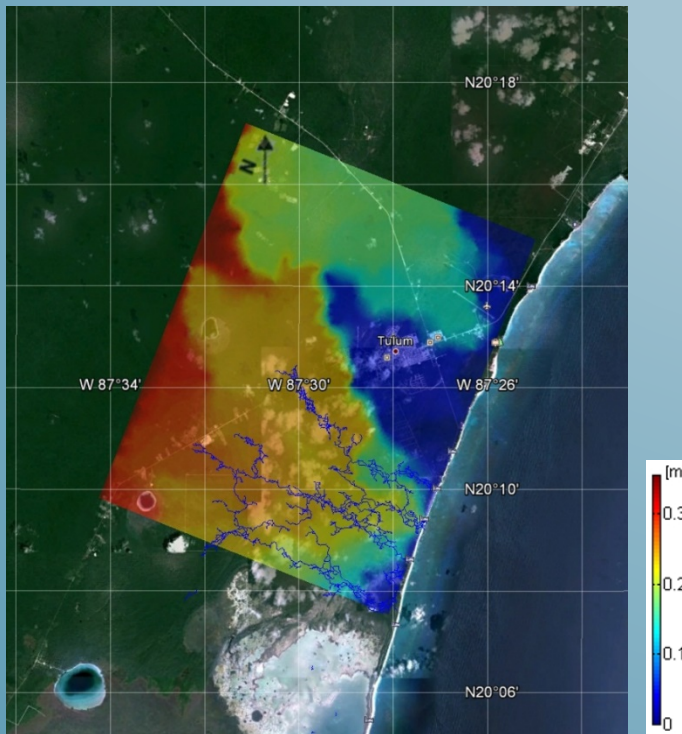
Major part of the flow passes through the conduits.

=> Flow traveltime from Tulum town to the sea very short.



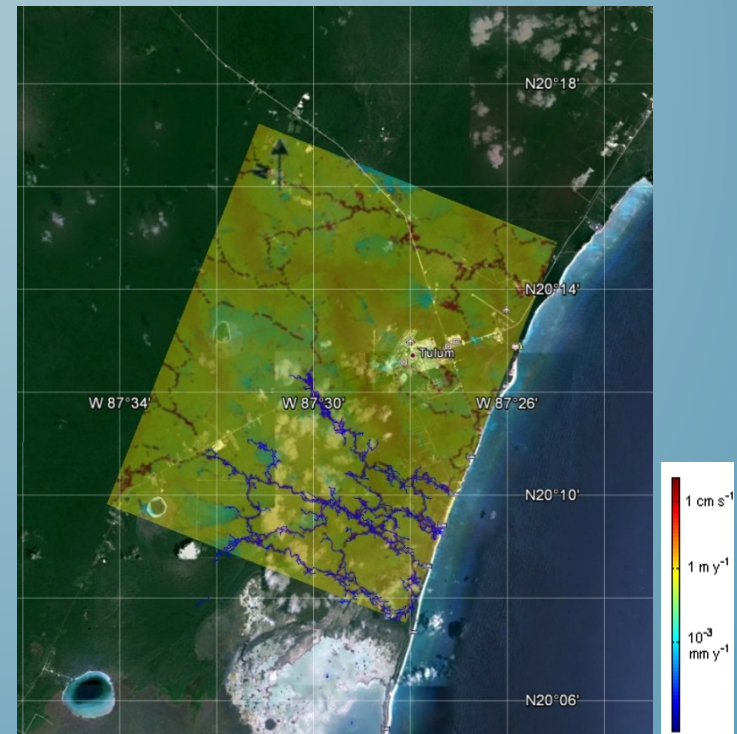
Piezometric map

hmax= 0.36 m



Velocity map

vmax=0.75 m/s



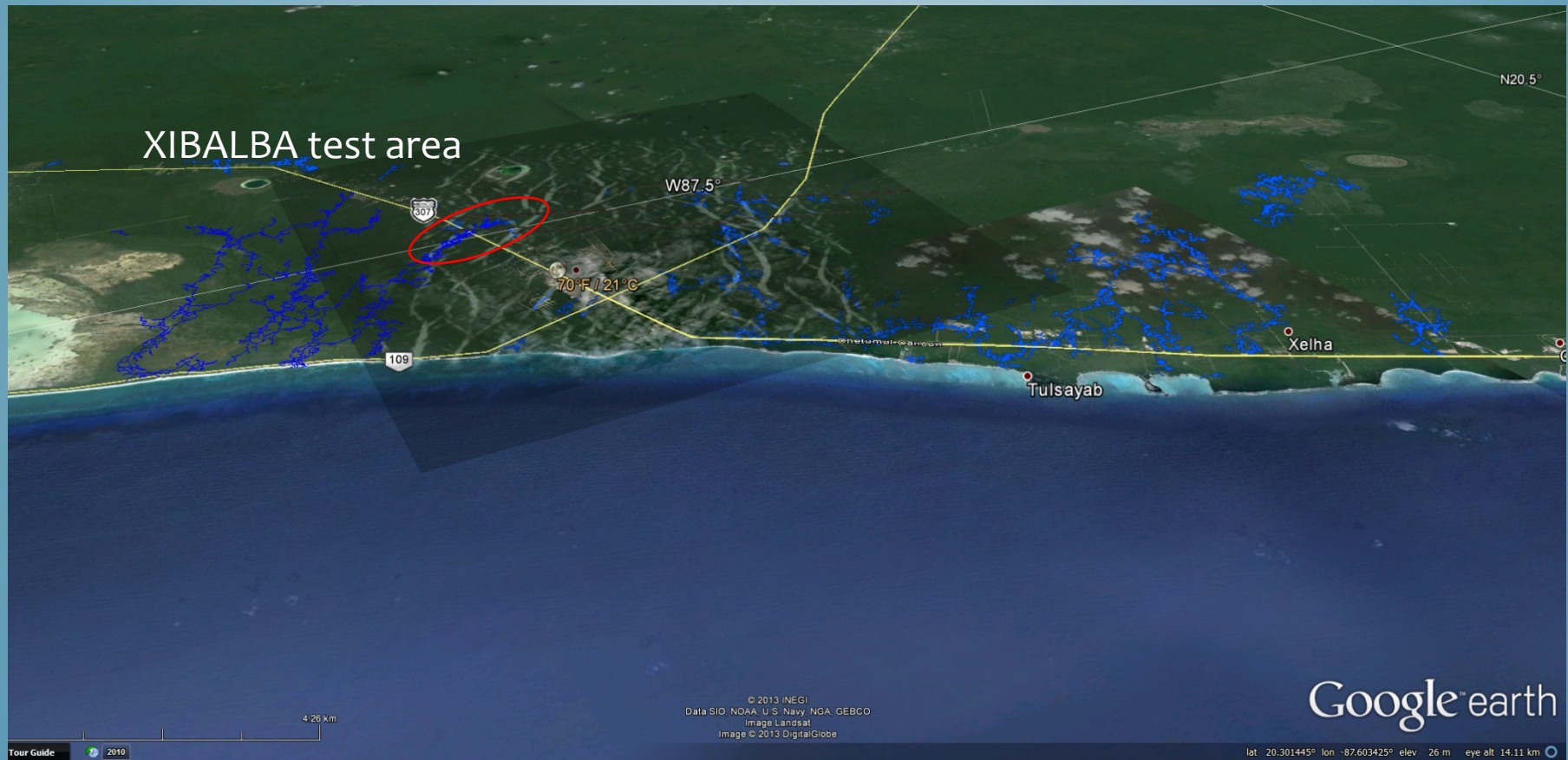
Plots from: C Vuilleumier et al. A method for the stochastic modeling of karstic systems accounting for geophysical data: an example of application in the region of Tulum, Yucatan Peninsula (Mexico), Hydrogeology Journal 21 (3)

Project Xibalba:

Acquisition of medium scale parameters for hydro-modelling
- 3D geometry laser scanning in underwater karst tunnels

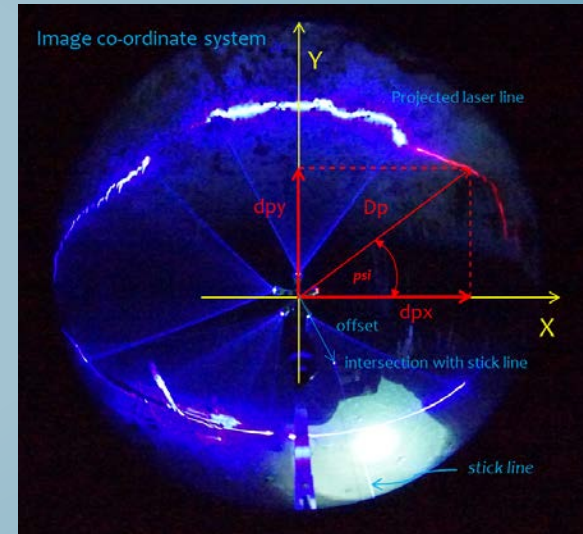
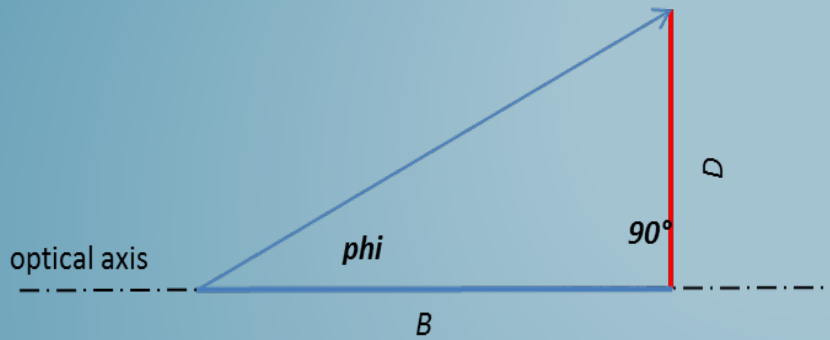


,The whole thing' – system surveyed by exploration divers



Cenotes





B: distance between a plane and the measurement location.

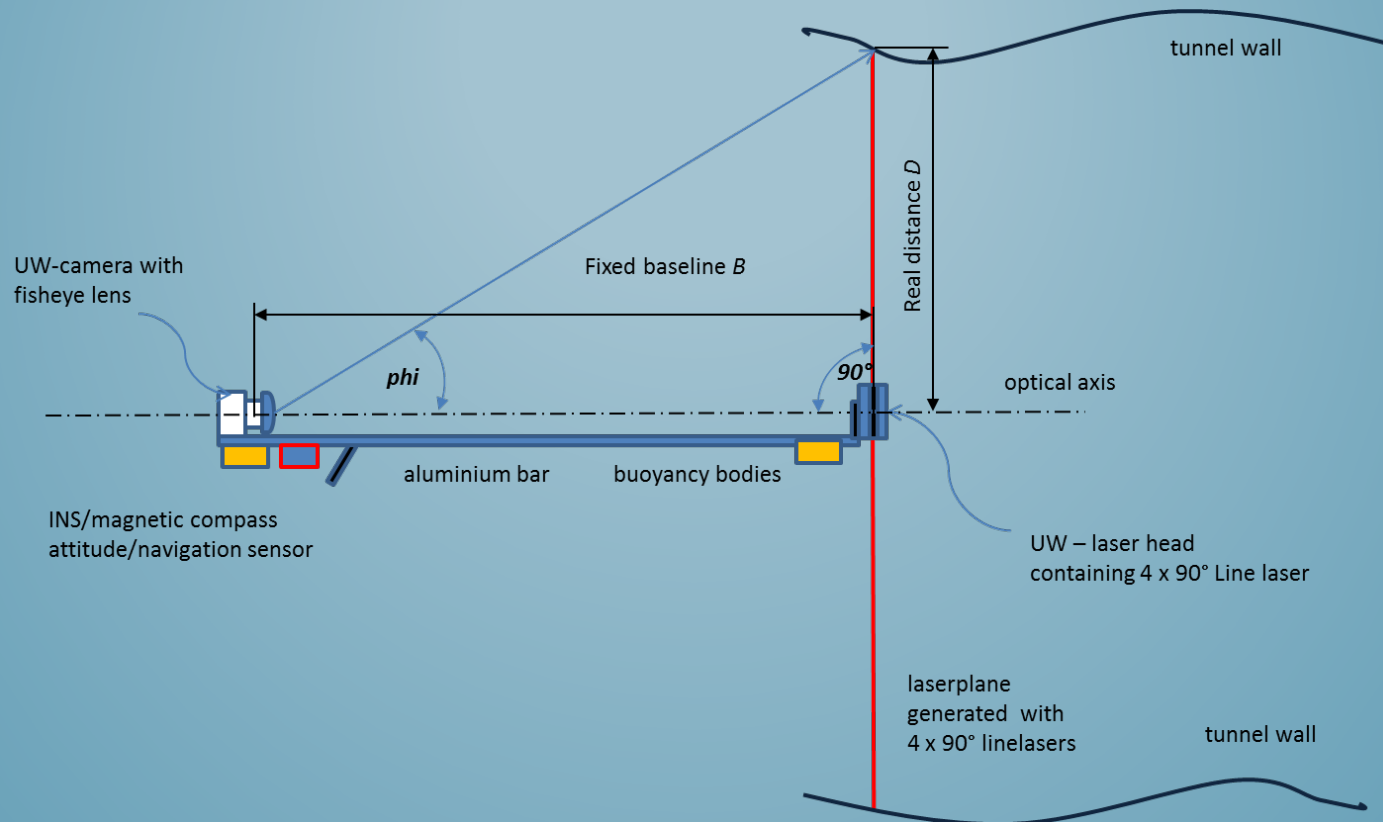
If plane normal to optical axis each distance in the plane can be derived from angle ϕ and distance B:

$$D = B \cdot \tan(\phi)$$

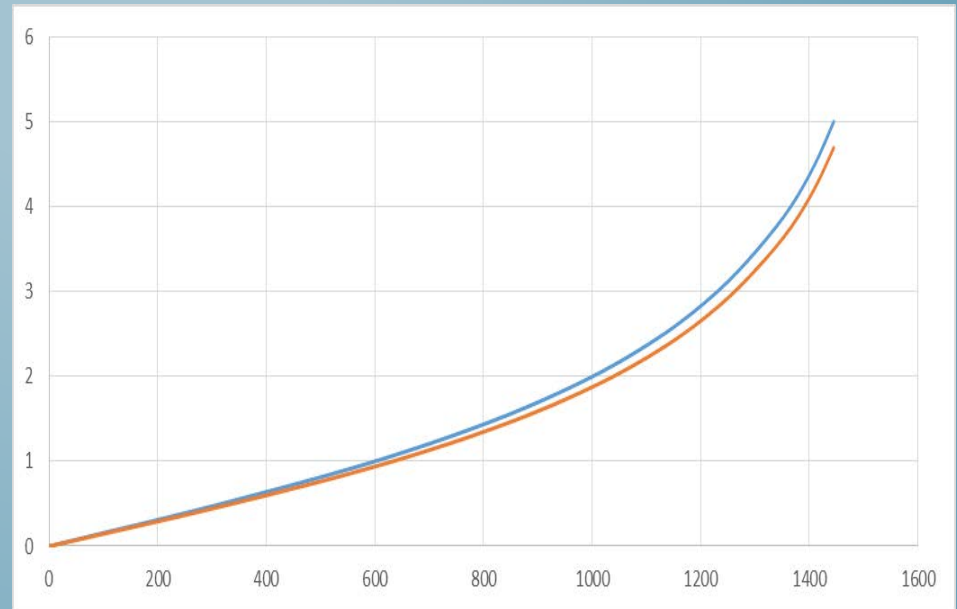
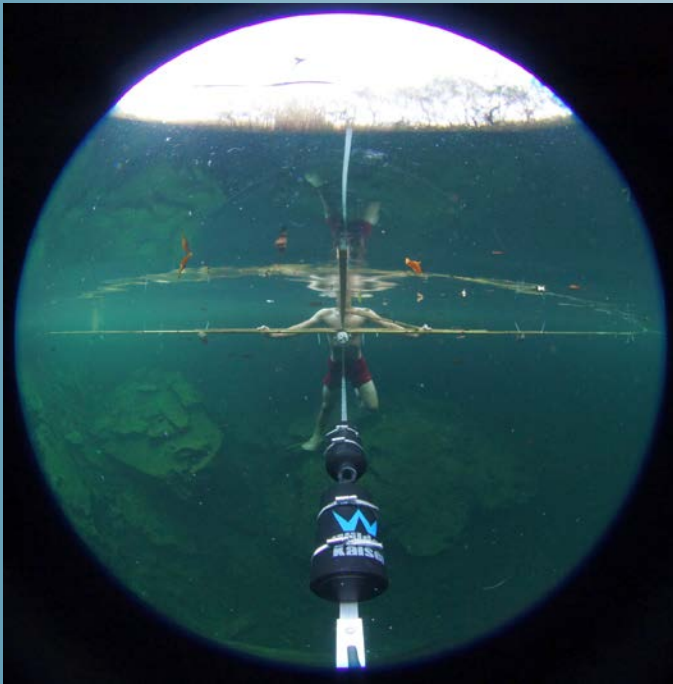
ϕ can be measured by means of an imaging system if relation between pixel distance in image D_p and ϕ can be expressed by a mapping function $D_p = f_m(\phi)$. This relation depends on lens system.

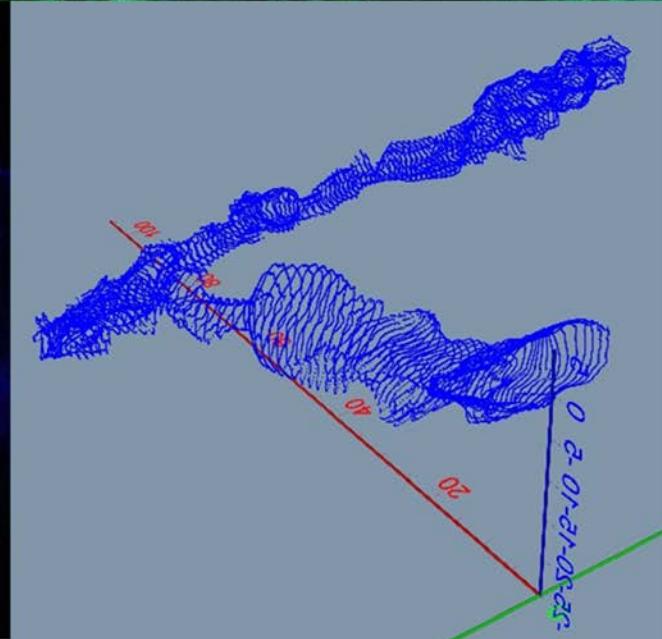
Thus
$$D = B \cdot \tan(f_m^{-1}(D_p))$$

Principle of a mobile measurement set up for cross section capturing of under water caves

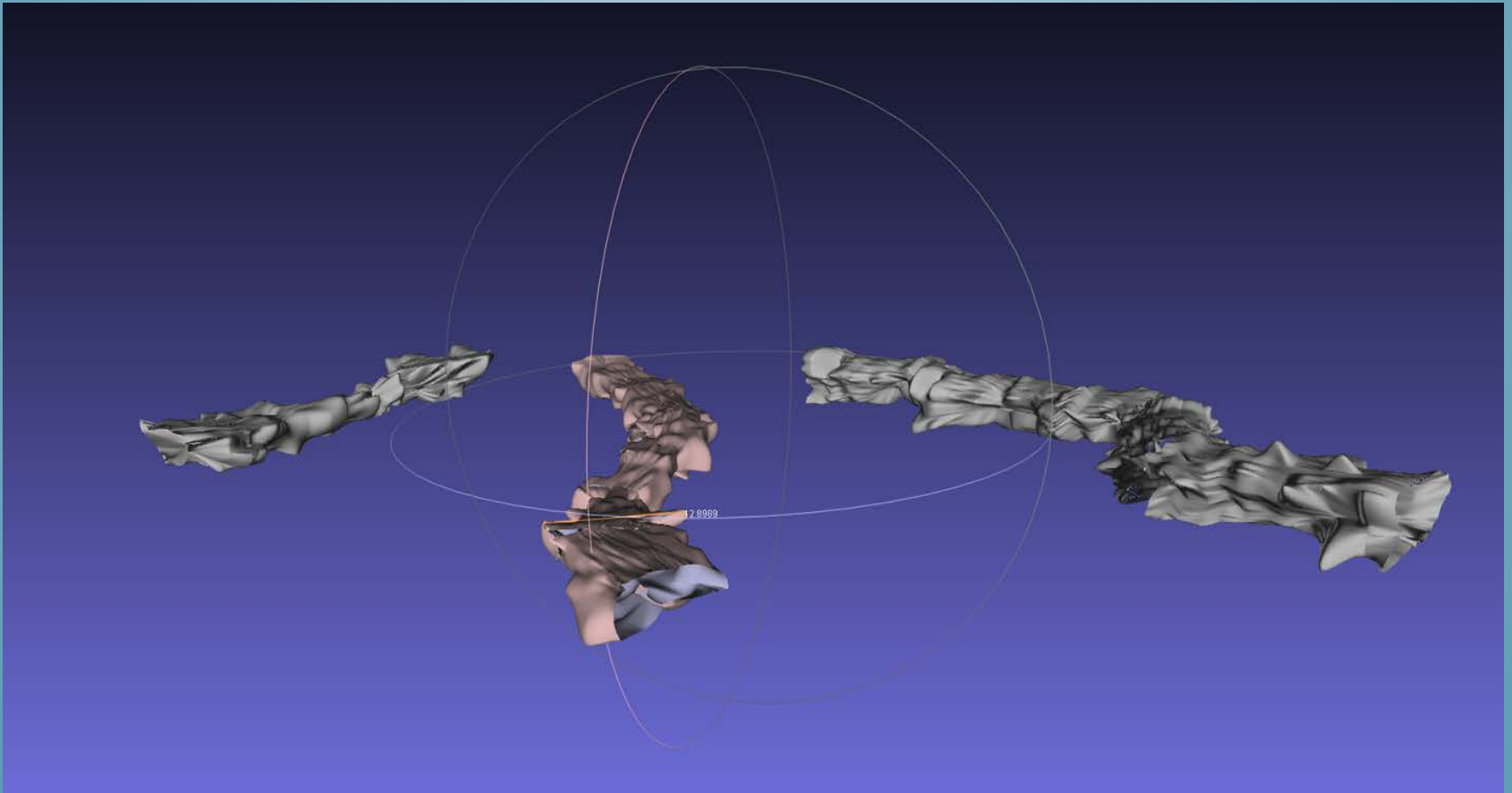


Laserscanner - Calibration for B=2m (2,03m)





Scans Cenote Cristal, Jailhouse, Tercier Cielo (2015)



Project Xibalba: Experimental Laser Flux Imaging System

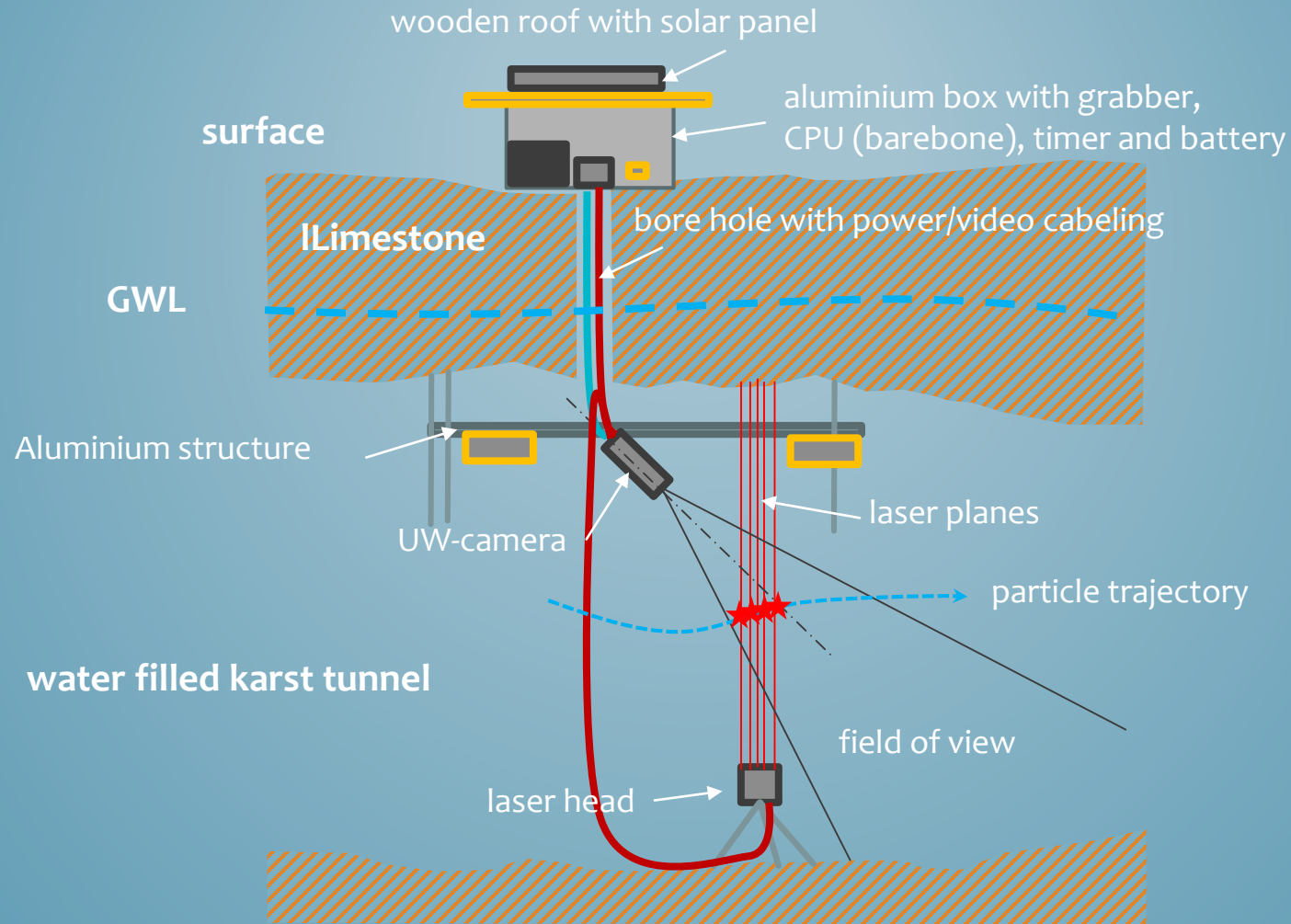


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BASIC IDEA AND SET UP



RAW DATA

- Sample Screen shots $ds=1.2$ cm



t1=0.595



t2=1.786



t3=2.989



t4=4.481

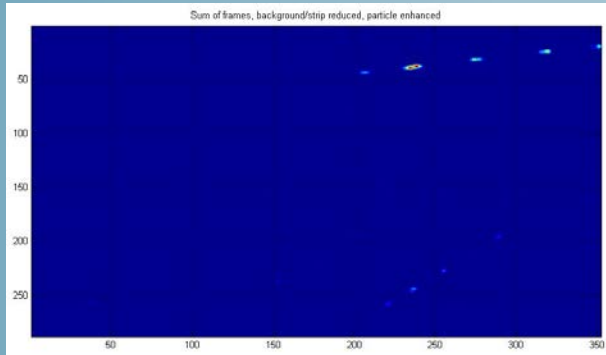


t5=5.955

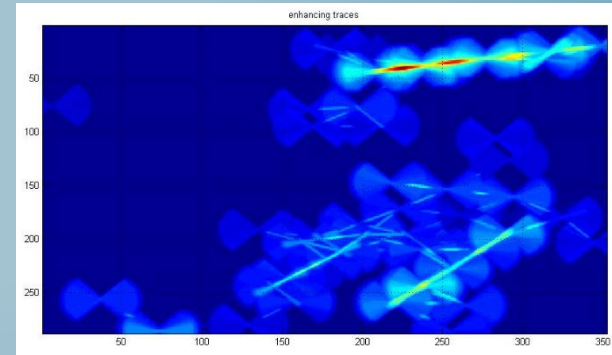
t	dt	v	
0.595			
1.786	1.191	1.01	
2.989	1.203	1.00	
4.481	1.492	0.80	
5.955	1.474	0.81	
normal	mean v	0.91	cm/s

Data Processing

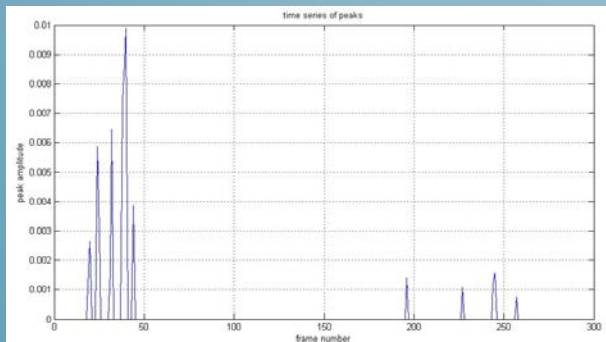
Particle enhancement



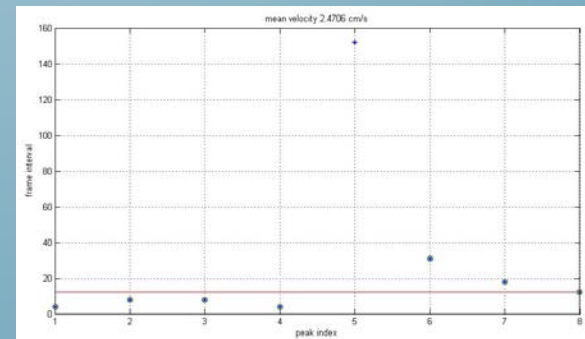
Searching traces



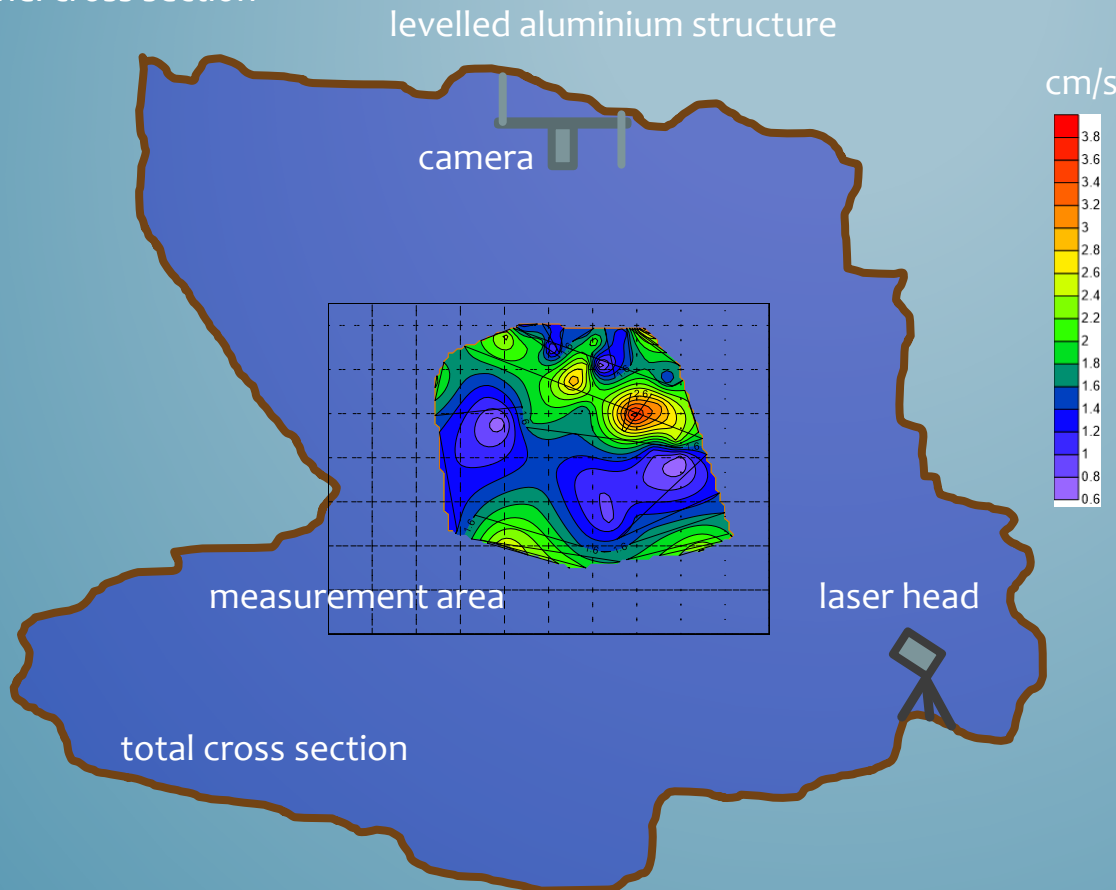
Finding peak series



Deriving velocities



tunnel cross section



Planar area:

Positive Planar Area: 1.176 m²

Flux through area:

Total volumes by: cm³/s

Trapezoidal Rule: 20160.1

Simpson's Rule: 20133.8

Simpson's 3/8 Rule: 20159.1

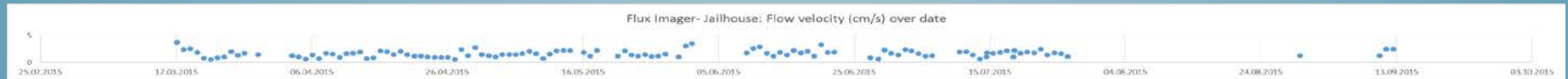
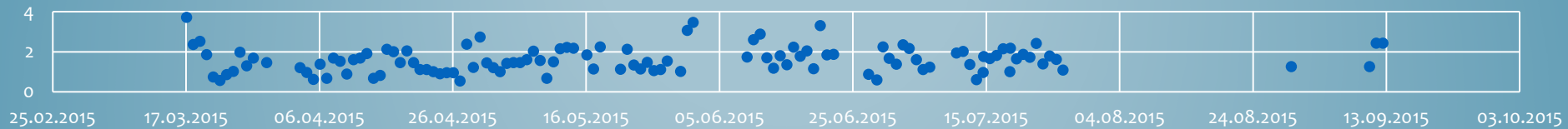
Flux: 20.15 liters/s

(extraploated to whole cross section up to 200l/s)

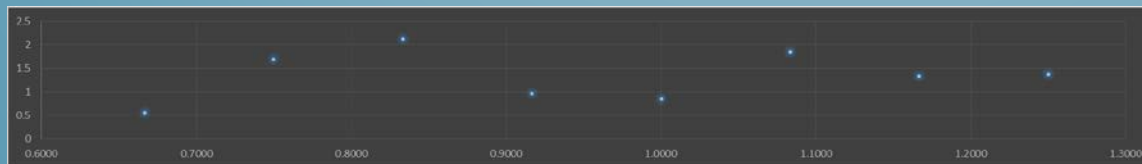
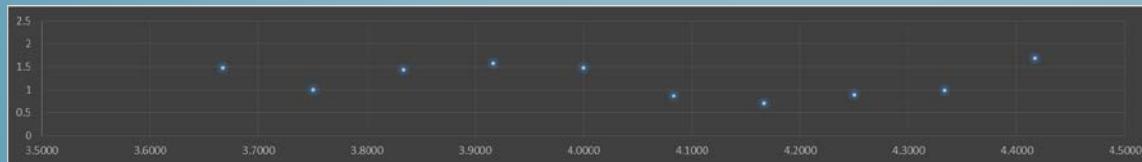
Flux Imager Jailhouse station

Long term series

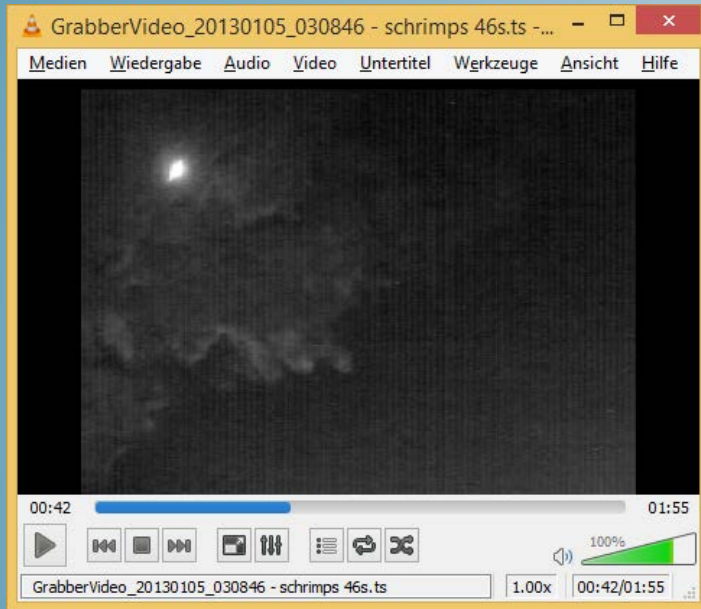
Flow velocity (cm/s) over date



Short term variations – time interval 2 hours



INTERFERING PHENOMENA - STYGIOBIONTS

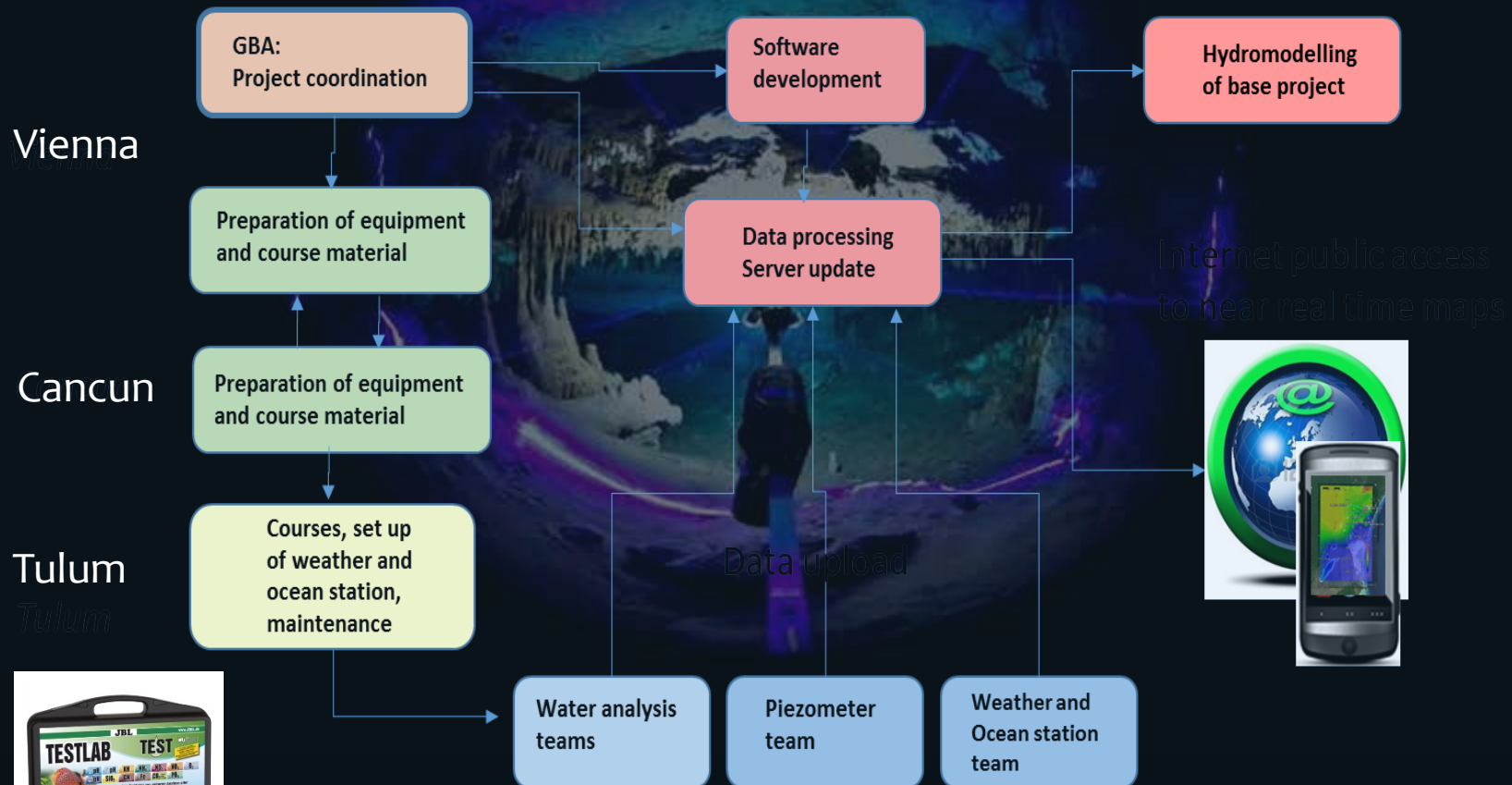
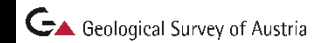


Right: *Niphargus ictus* (<http://en.wikipedia.org/wiki/Niphargus>)

Left: *Proasellus cavaticus* (<http://www.karstforschung.at/H%F6hlenfauna.htm>).

Project Xib_TCS:

Citizen supported groundwater monitoring in Tulum



http://tcgi.banana-tree.net/TCgji/mexi Home - Mexico tcgi.banana-tree.net Textblock

xib tcs

en es

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[Mitmachen](#)

Aktuelle Karten

Hier gibt es aktuelle Karten verschiedener Grundwasserparameter

Unten rechts ist eine Liste von herunterladbaren Karten mit Datum. Die Karten werden in Wien aus den Daten der Messteams in Tulum erstellt. Gemessen und dargestellt werden Temperatur, Leitfähigkeiten, Salinität, Nitrit, Nitrat, Phosphat, Wasserhärte. Bei genügend Karten wird ein movie bereitgestellt.

Legende:
Cond ... elektrische Leitfähigkeit
GWL Grundwasserspiegel
Temp ... Temperatur

[« zurück](#)

Neuigkeiten

Hallo Johanna! Liebe Grüße nach Spanien! Wie isses Wetter?

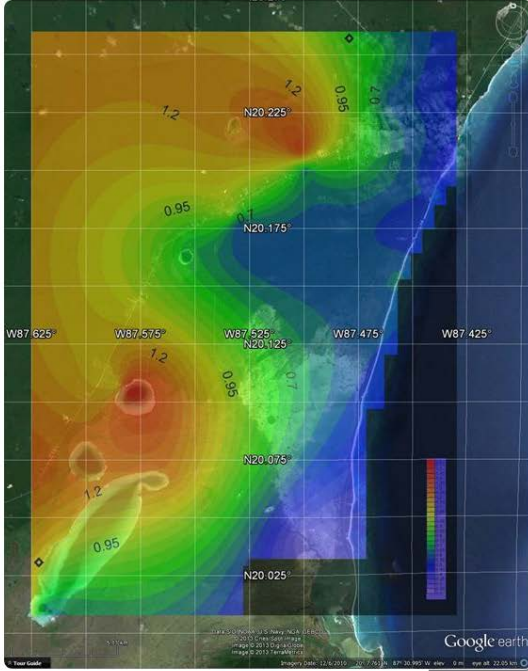
Im Moment bauen wir noch die Website auf. Schaut schon ganz gut aus und ...

[» mehr](#)

Aktuelle Karten 1

Hier gibt es aktuelle Karten verschiedener Grundwasserparameter

[» mehr](#)



Cond_08112016

Google earth



Gracias!

