Acquisition of 3-D geometry data in underwater karst tunnels by laser scanning

Innovative method development in the underwater cave system of Tulum/Mexico

Arnulf Schiller

arnulf.schiller@geologie.ac.at

Overview

- Context of the development
- Problem statement
- Survey Area
- Basic idea
- Principle
- Realization
- First field test 2013
- Second field test 2014
- Conclusion and next steps

Context of the reserach

2004: First contact with Amigos de Sian Ka'an

2006: Ground test measurements: GE, EM

2007: First aerogeophysical survey and ground measurements in Tulum

2008: Second aerogeophysical survey and ground measurements in Tulum

2008 - Project Xplore

2009: Aerogeophysics near Cancun and Chetumal, Socorro, GE in Tulum

2010: Large ground geophysical campaign (GE/ERT, GPR, borehole geophysics, GWL monitoring, water analysis).

2011: High precision GPS GWL survey, retrievement of GWL loggers, water analysis
2012: High precision GPS GWL survey with tides observation, water analysis

2012 - Project Xibalba

2012-2015 - Tidal scanning, optical flow and geometry measurements in conduits, with innovative laser devices, **aerogeophysics data reprocessing**

Partners

Geological Survey of Austria

Amigos de Sian Ka'an

Technical University of Denmark

Université de Neuchâtel – Philippe Renard

Karl-Franzens-Universität Graz – Steffen Birk

École Polytechnique Fédérale de Lausanne – Marco Philipponi

ETH Eidgenössische Technische Hochschule Zürich, Swiss Federal Institute of Technology Zurich – Wolfgang Kinzelbach

Secretaría de Marina Armada de México

CINDAQ – Sam Meacham

Xibalba Dive Center – Robbie Schmittner

CICY Centro de Investigación Científica de Yucatán, A.C. – Mario Rebolledo-Vieyra

CONANP

Arnulf Schiller - Geological Survey of Austria 4

Project Funding

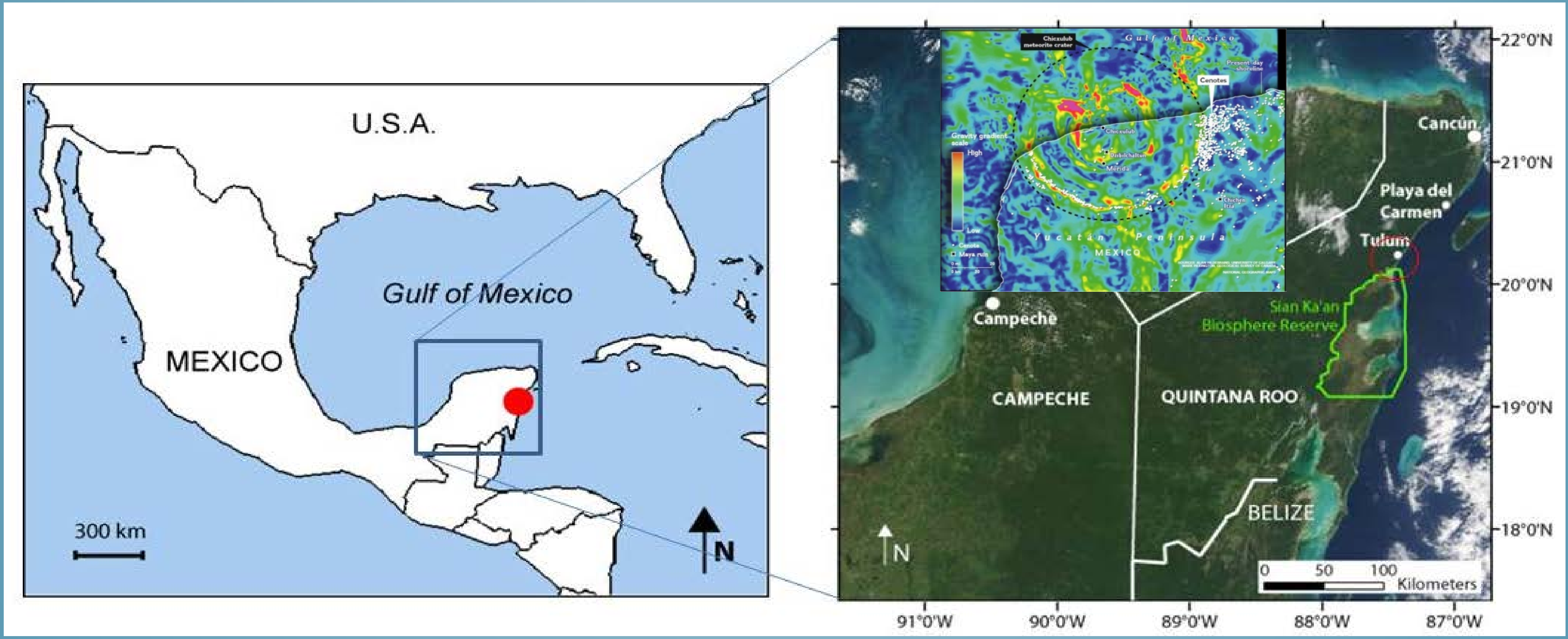
The Nature Conservancy, Unesco (Flight Surveys Tulum 2008/2009)

Austrian Science Fund (projects HIRISK, Xplore, Xibalba)

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

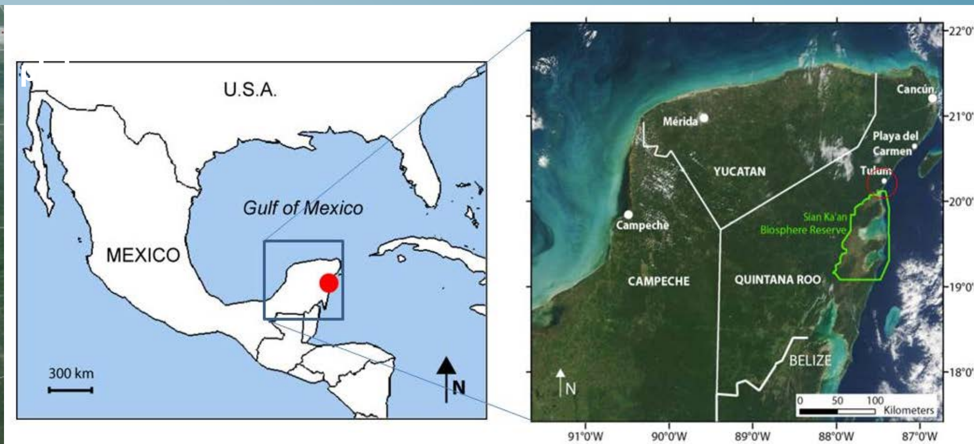
Swiss Science Fund (project Xibalba)

Geographical overview

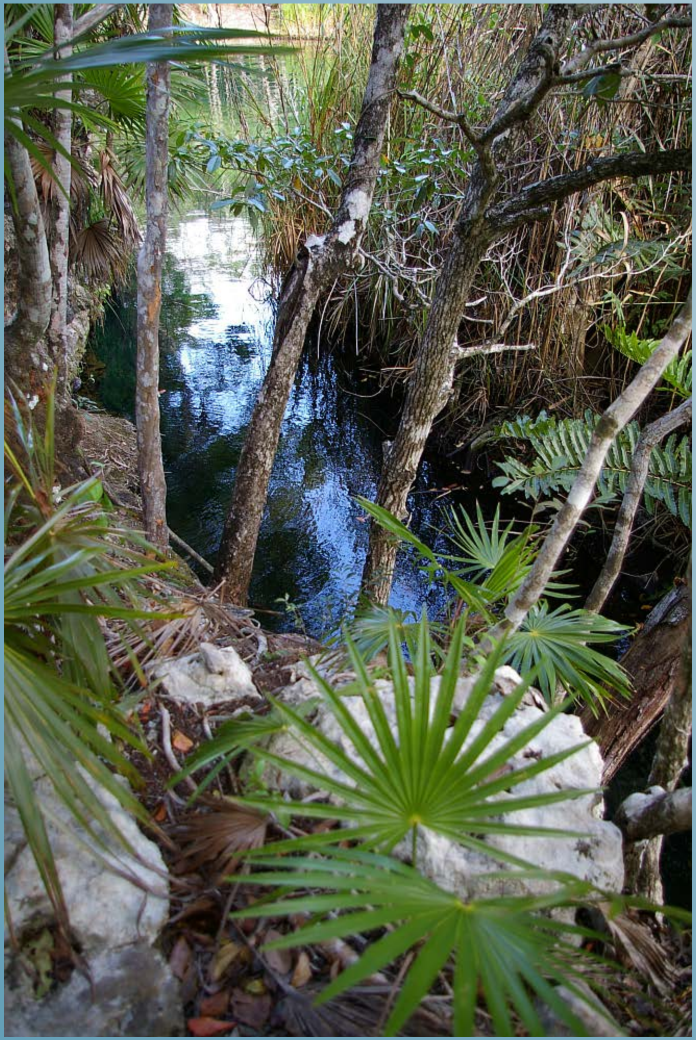


The Survey Area – Tulum Karst Plains

- **Huge difficult accessible coastal bush and mangroves**
- **limestone several 1000 metres thick**
- **flat topography (0 - ~70 m above mean sea level)**
- **thin soil cover – limestone exposed at the surface**
- **Known conduits explored by cave divers**
- **Freshwater layer above saltwater body**
- **Tidal variation of groundwater and halocline level reaching inland**



Cenotes



General problem statement (project XIBALBA)

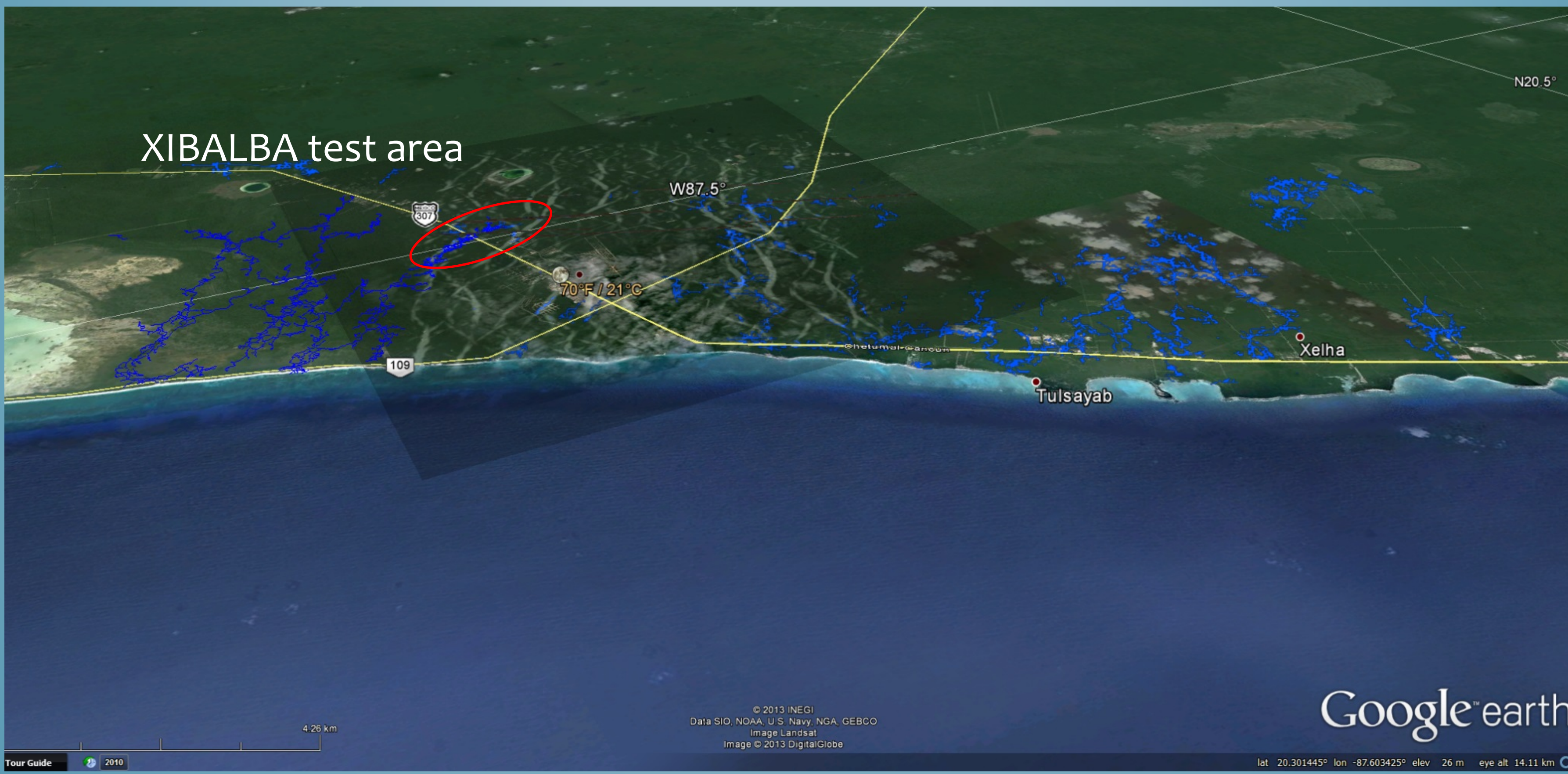
- Analysing the carst network with respect to structure and development as well as the definition of crucial parameters for modeling

- Application of standard methods and development of innovative methods for the acquisition of crucial data as

    - geophysical data governing hydrological modeling (ground and airborne geophysics)
    - hydrological parameters (measurement and logging of groundwater level, halocline level, flow data, including tracer tests, porosity).
    - **geometric data of conduits** (survey data, **3d geometry**)

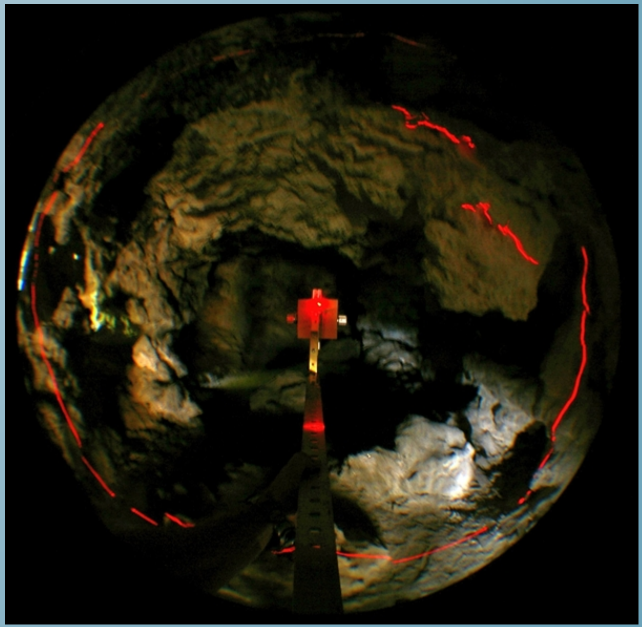
- Test of methods and retrieving important small scale/long time data within an easily accessible and representative testing site

‚The whole thing' – system surveyed by exploration divers



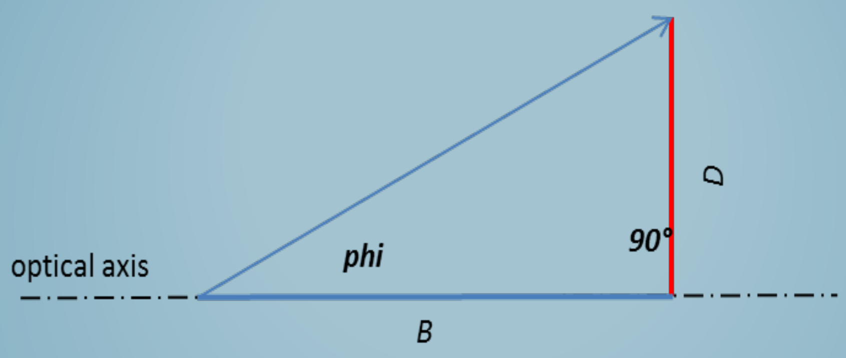
2013 survey area for geometry and flux test measurements

Laser geometry measurement – basic principle



Field test Einödhöhle (near Vienna, dry), f=4mm, 4 sec
Cross section about 3x2 m. Laser line projected on cave wall.

Basic Principle – Triangulation via Mapping



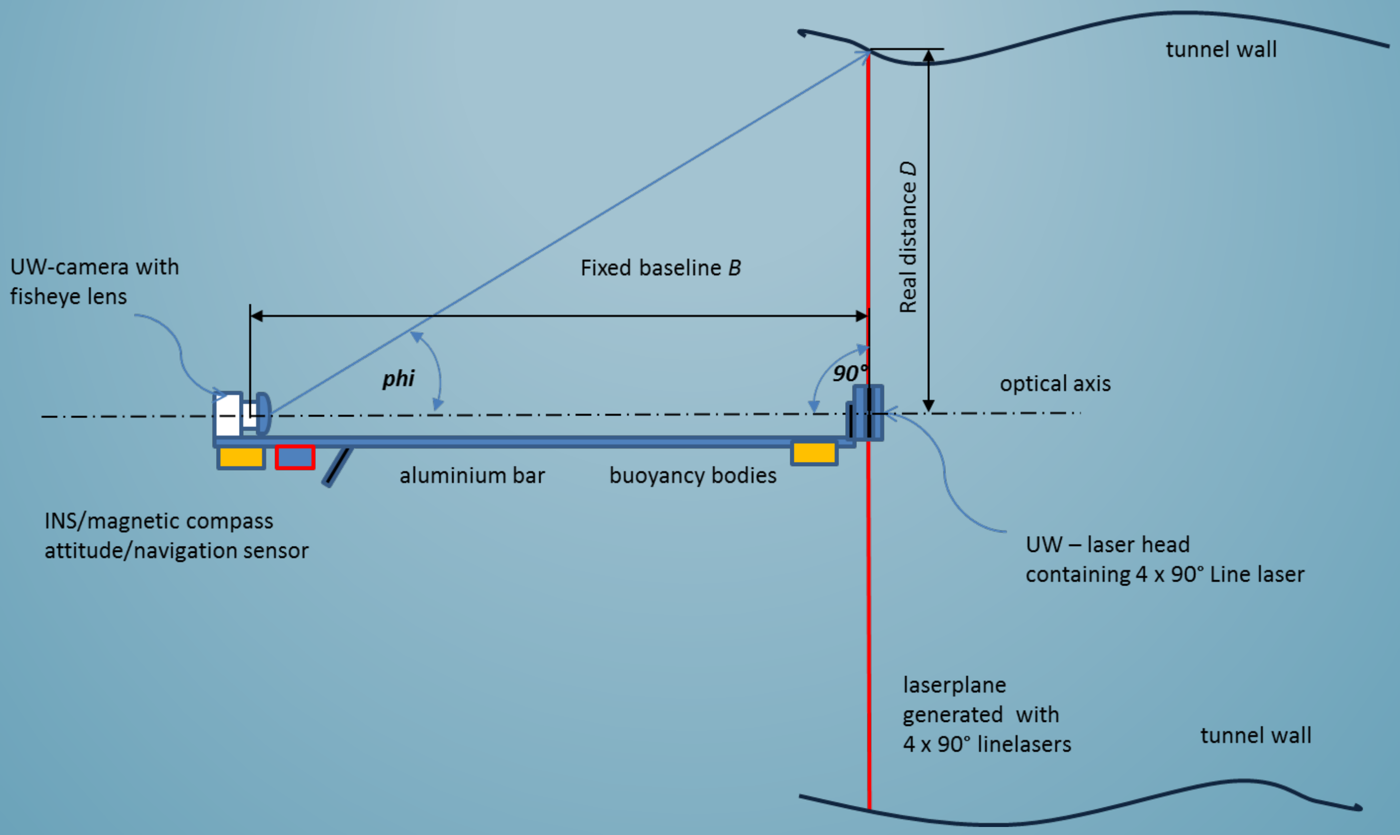
B: distance between a plane and the measurement location.
If plane normal to optical axis each distance in the plane can be derived from angle *phi* and distance *B*:

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

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

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

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



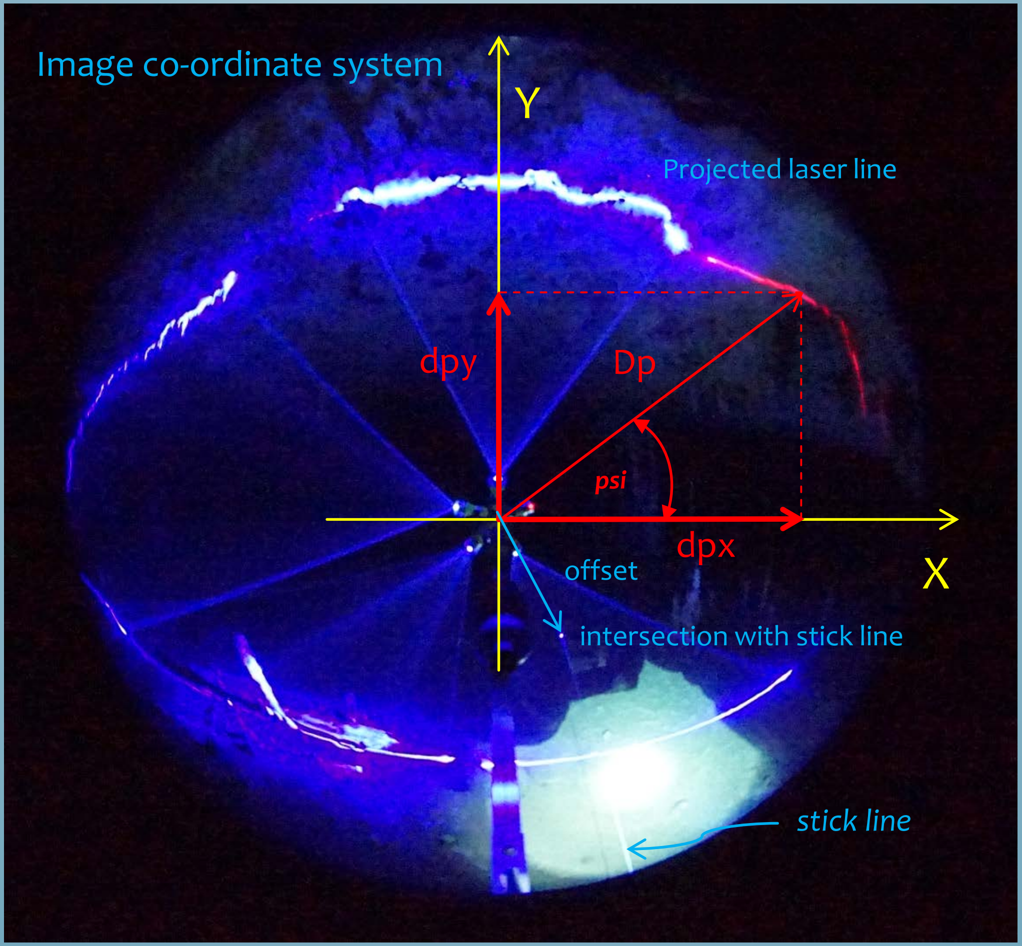
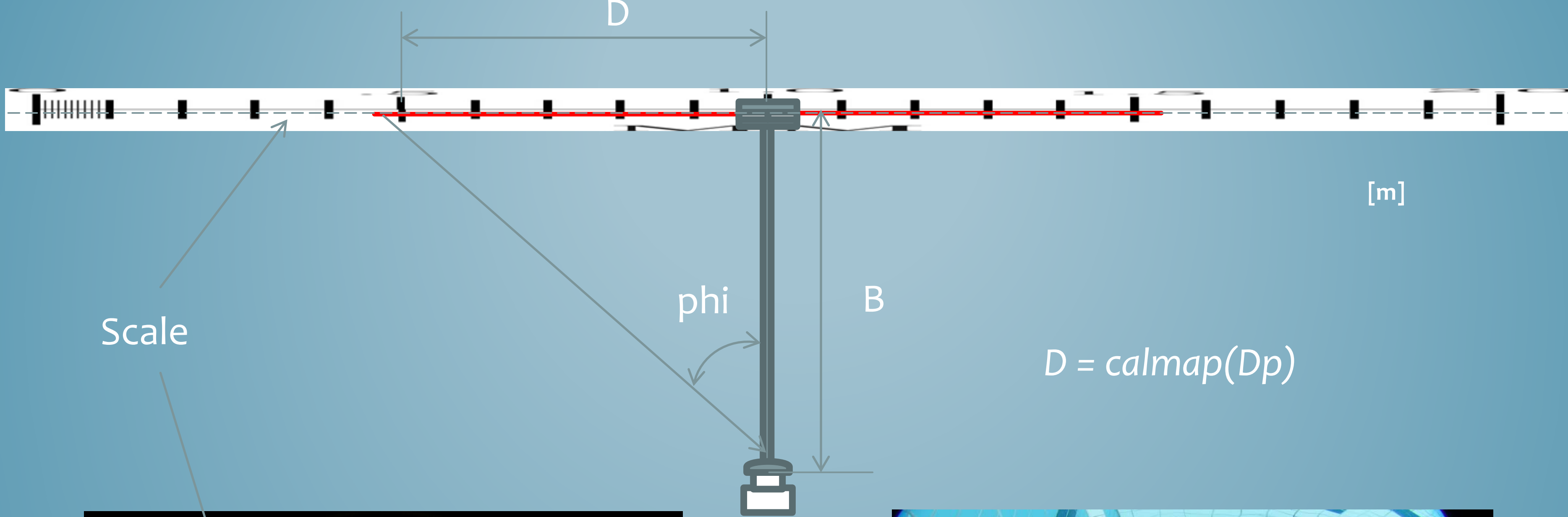
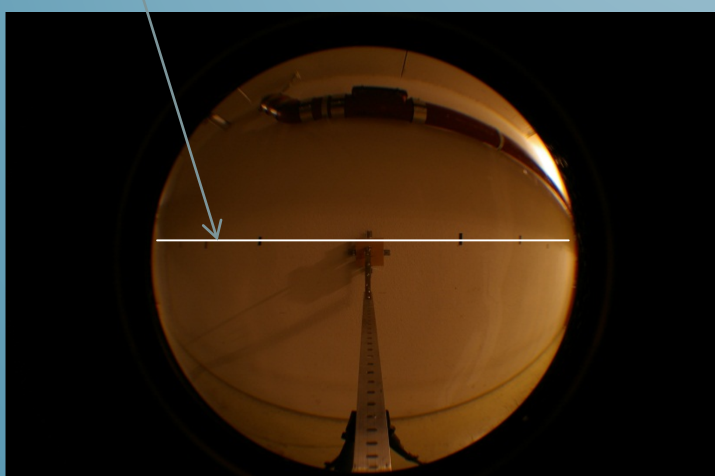


Image co-ordinate system
Y
Projected laser line
dpy
Dp
psi
dpx
offset
X
intersection with stick line
stick line

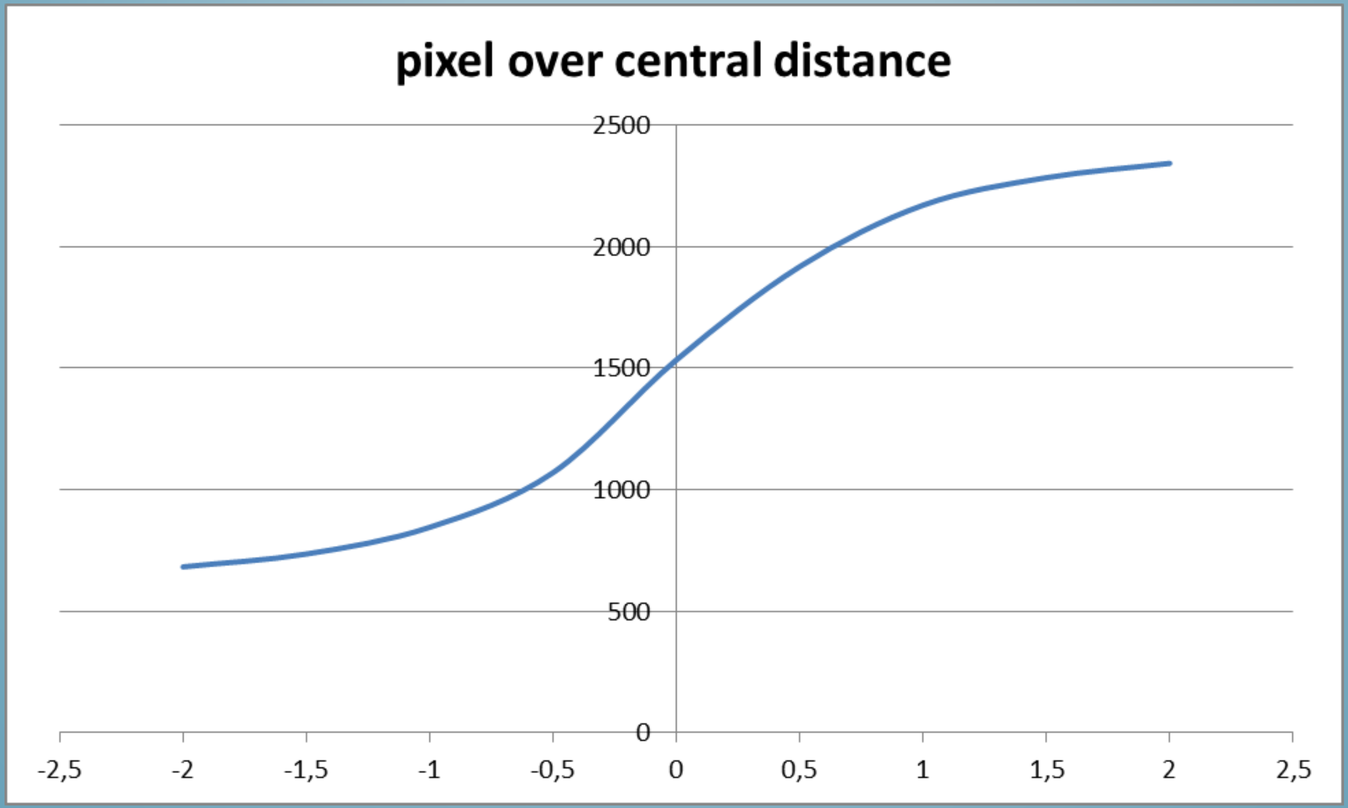
Calibration: Direct mapping of pixel distance to real radius



D = calmap(Dp)



Calibration function



real distance [m]

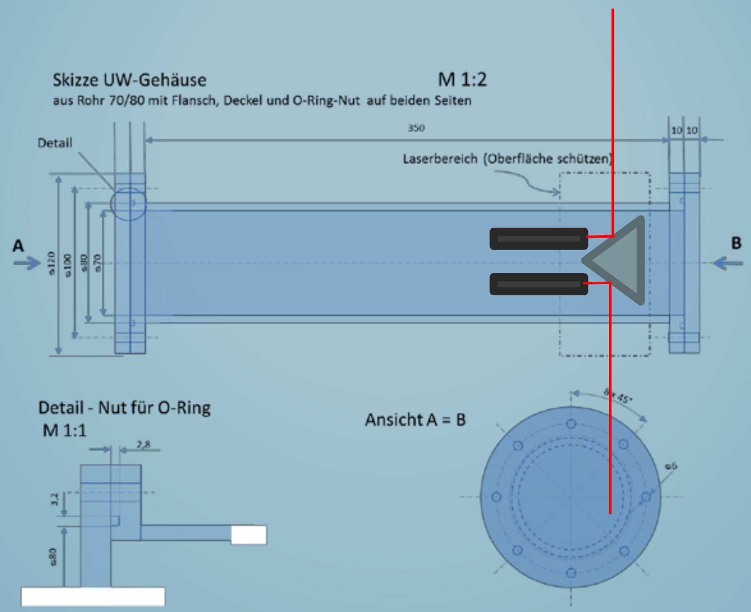
Components – Imaging system

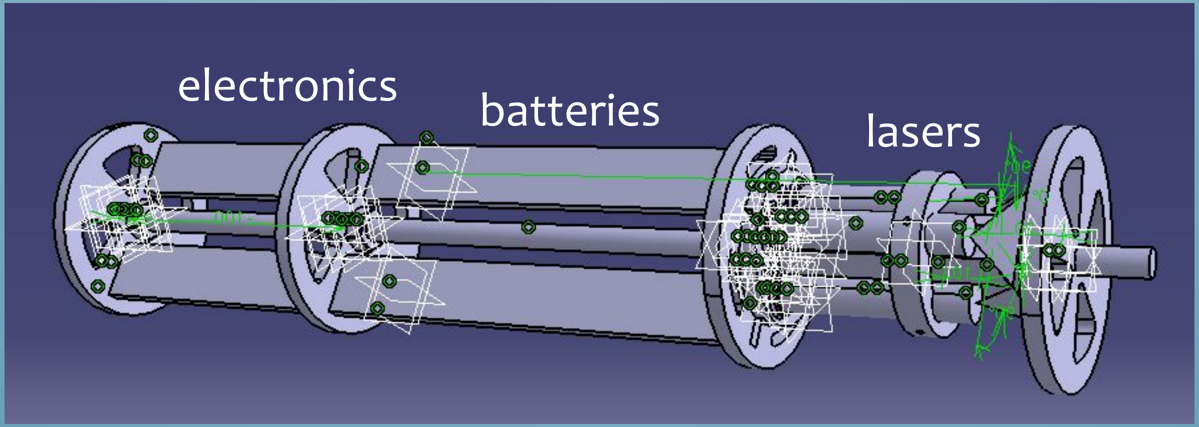
Sigma Objektiv AF 4.5mm 2.8 EX DC HSM Zirkular Fisheye

Sony Alpha 65 (EVIL) Gehäuse (SLT-A65V)

Ikelite under water casing for Sony Alpha A65 + fisheye dome port

Components – structure of laser head





Cenote Escondido seen through the imaging systems eye

Arnulf Schiller, Geological Survey of Austria
arnulf.schiller@geologie.ac.at

Measurement procedure:

1) If no stickline present – conventional surveying of the tunnel/applying stick line

2) Adjusting device: baseline length, camera parameters and buoyancy

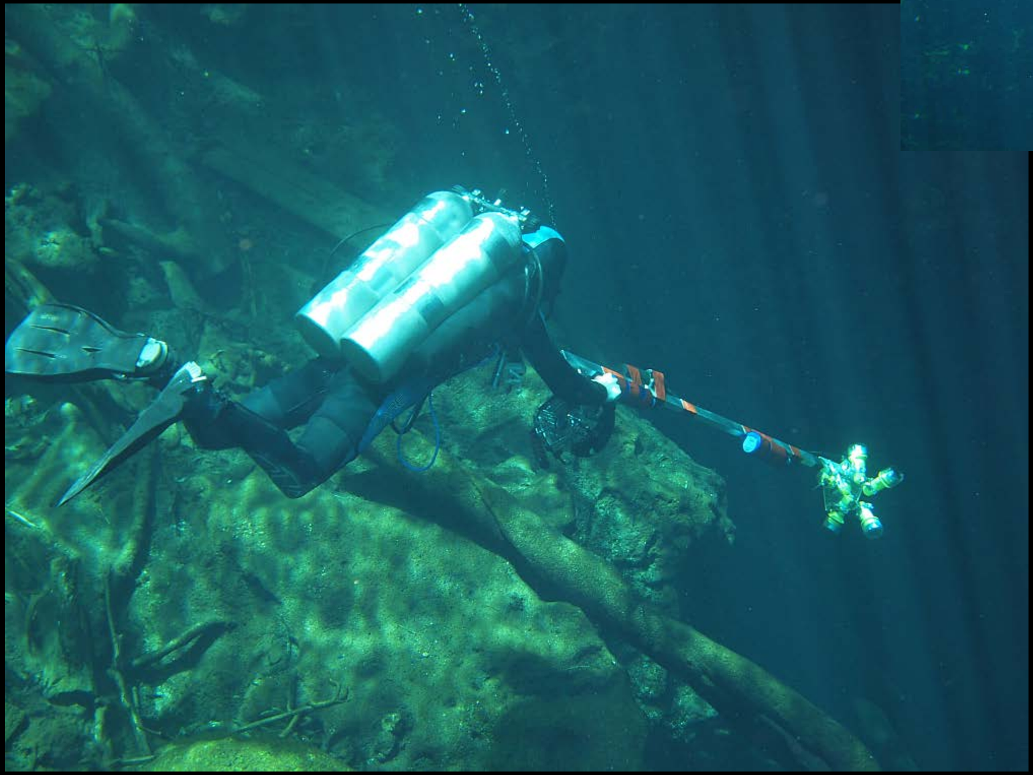
3) Constant movement along stickline

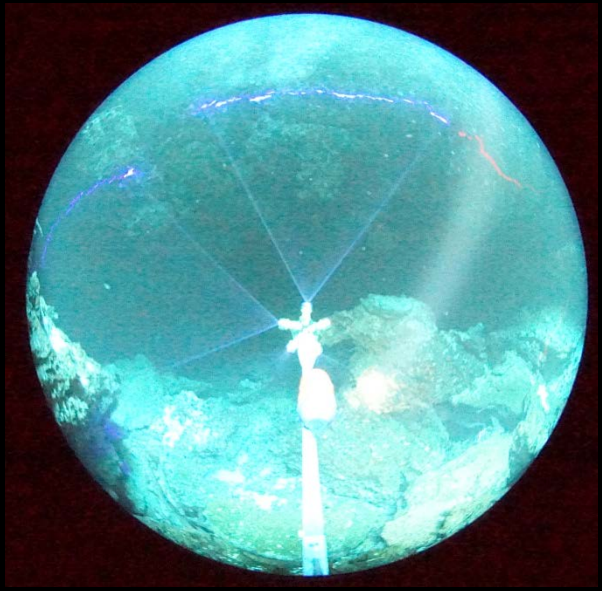
4) Horizontal leveling of the device and orientation of device parallel to stick line

5) Capturing images in constant distances along stickline

First field test 2013

Cenote Escondido -
Richie diving with prototype into
A-tunnel





Arnulf Schiller, Geological Survey of Austria arnulf.schiller@geologie.ac.at

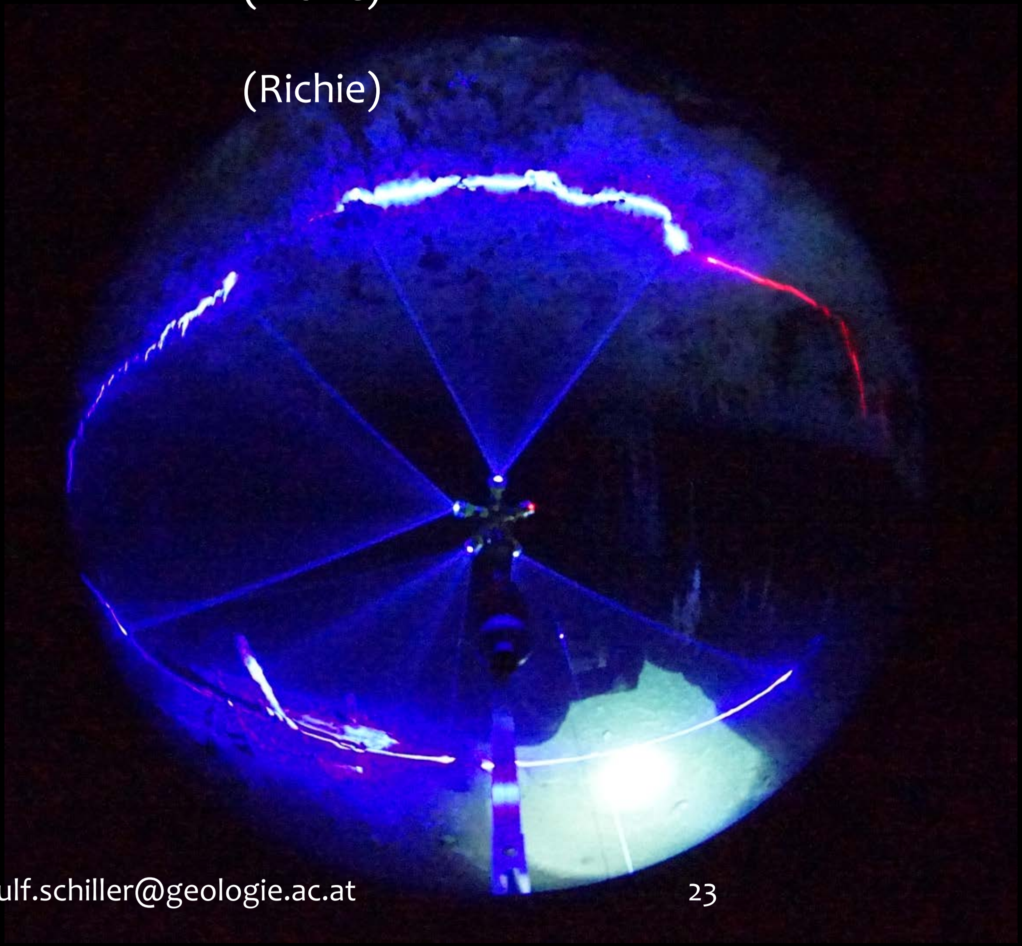
Laser Cross-Section Scanner

Cenote Maya Blue (Escondido)

A-tunnel

- first test:	125 shots	(Robbie)
- second test:	77 shots	(Richie)

Dead zone (third test) :	71 shots	(Richie)



First underwater test – typical image data

Data processing

1) Reviewing and editing the image data

Each image:

2) Digitizing of laser line and intersection point of laser plane with stick line (automatically)

3) Transformation of line data from image system to cross section system with mapping function

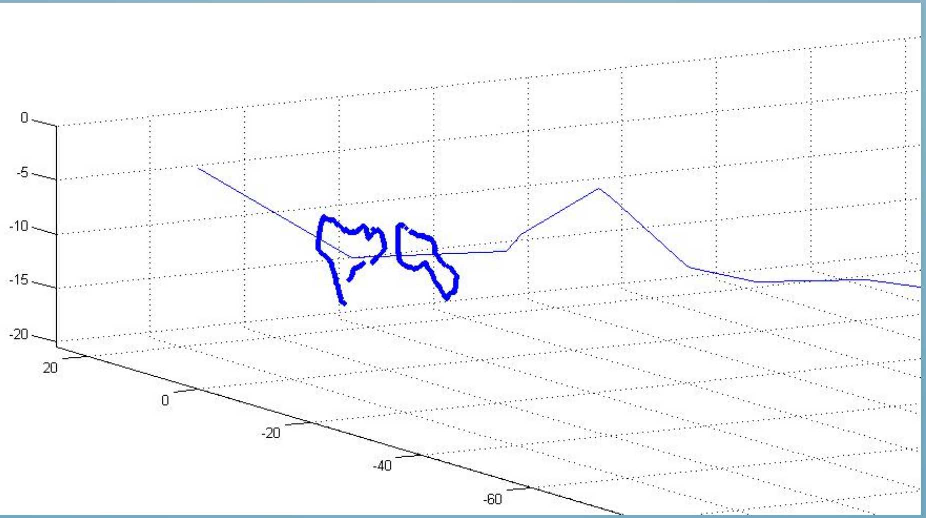
4) Defining x,y offset of device axis to stick line with mapping function and refering the cross-section to stick line.

All cross sections:

5) Merging cross section data and stick line data to => raw 3D-model

6) Oversampling of measured cross section by inserting interpolated cross sections (kind of morphing technique) => interpolated 3D-model

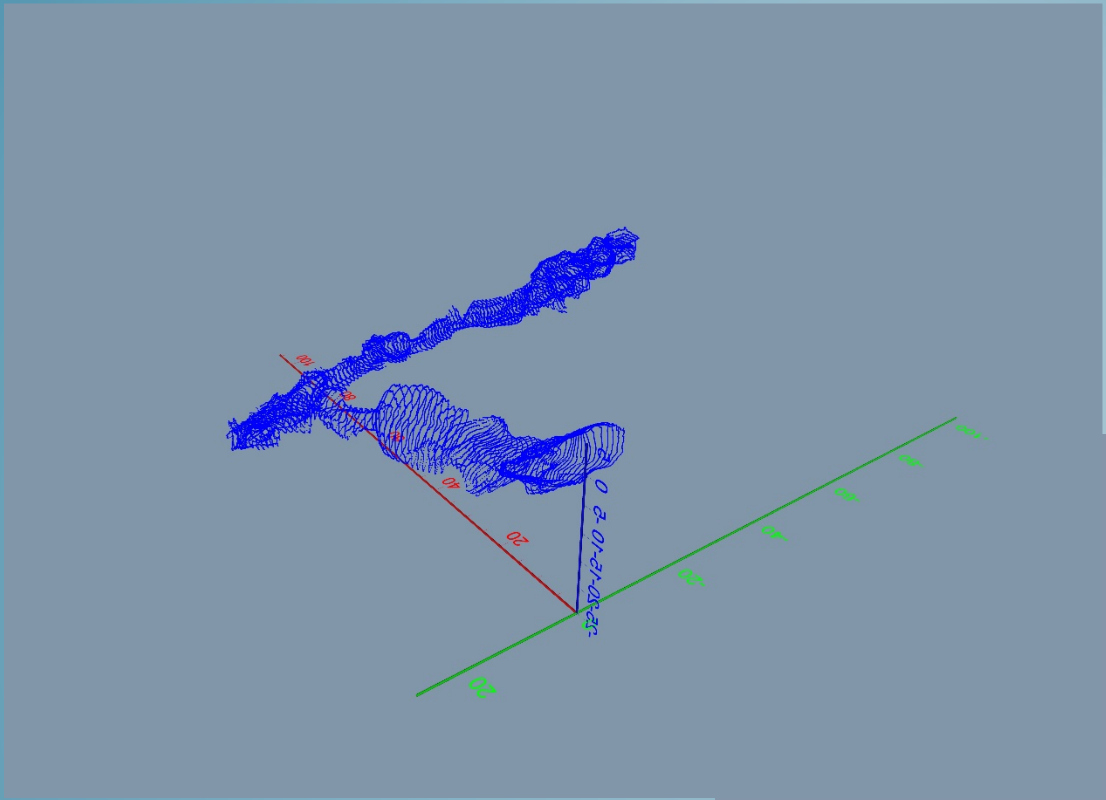
Dead zone -
stick line data and
2 perimeter shots

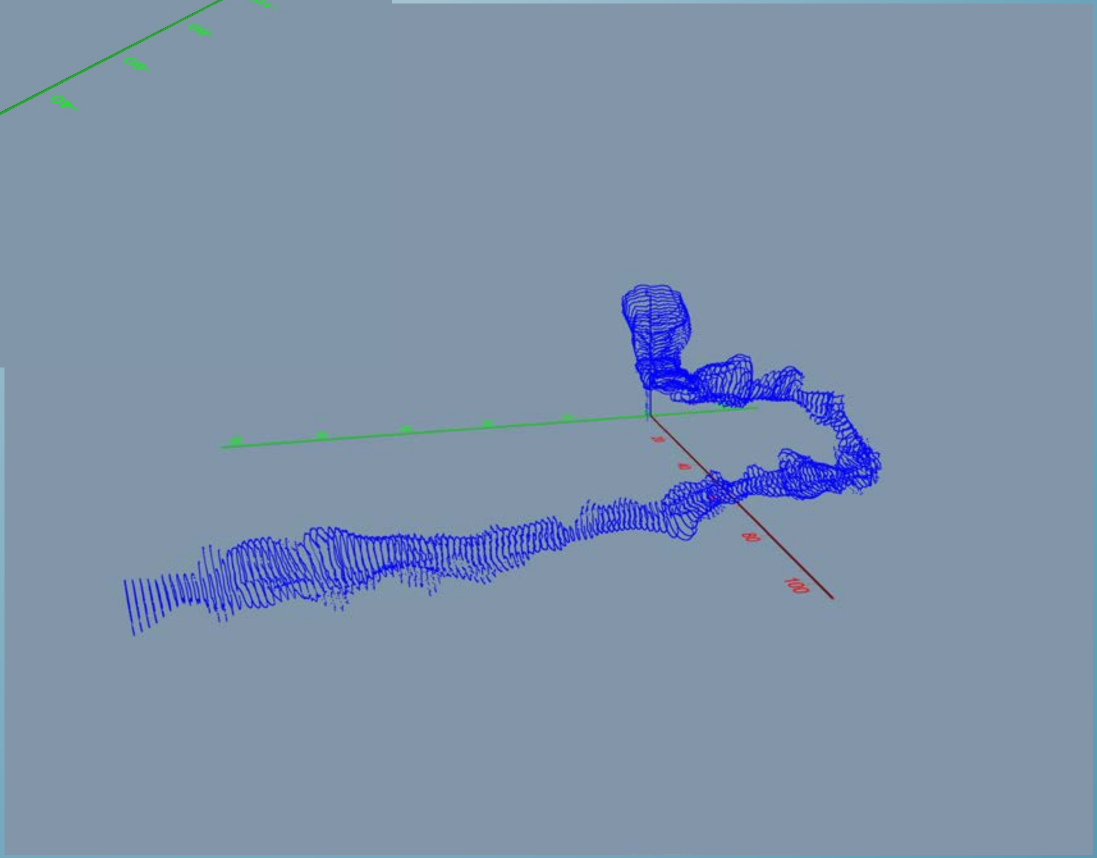


Results: Dead zone

71 perimeter shots

Interpolated from spacing 3m to spacing 1m





Dead zone 3D model

Dead zone 3D model

Summary of first field test 2013

- 273 shots which is equivalent to about 800 tunnel meters done in 4 dives
- blue lasers successful – red one significantly absorbed in fresh water layer
- 2 blue lasers ran hot and failed – already fixed
- Calibration function derived for B=123 cm
- Digitizing semi-automatically
- mapping to real cross section
- Interpolated 3D model

Field Survey 2014

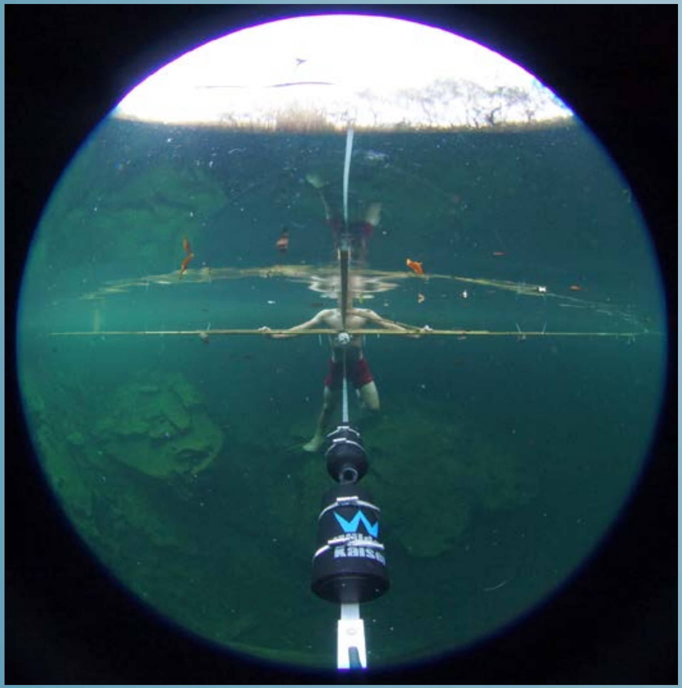
- Set up of test site in tunnel with 2 bore holes for cabeling to under water devices (data transfer, power)
- Laser water flux monitoring in under water cave
- Tracer test, water sample analysis
- Laser cave geometry measurement with improved device
- Bore hole geophysics in wells central and aside the tunnel
- Geoelectric tomography
- Rock sampling

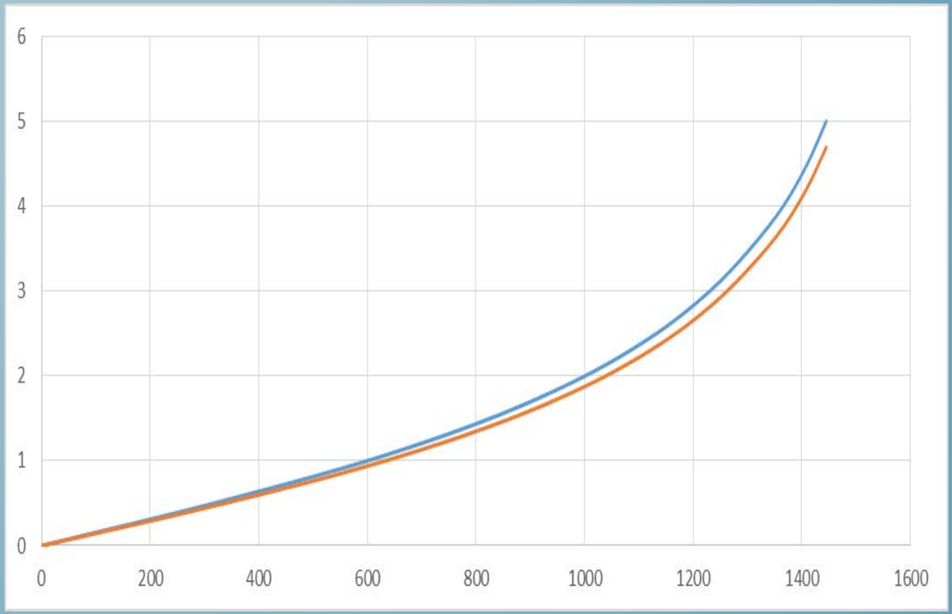
Tulum 2014 – High resolution geometry measurement with improved device

Test site at Cenote Jailhouse:

Tunnel length 43 m
53 shots
mean separation 83 cm
1 trial failed (no light)
Second trial succesful

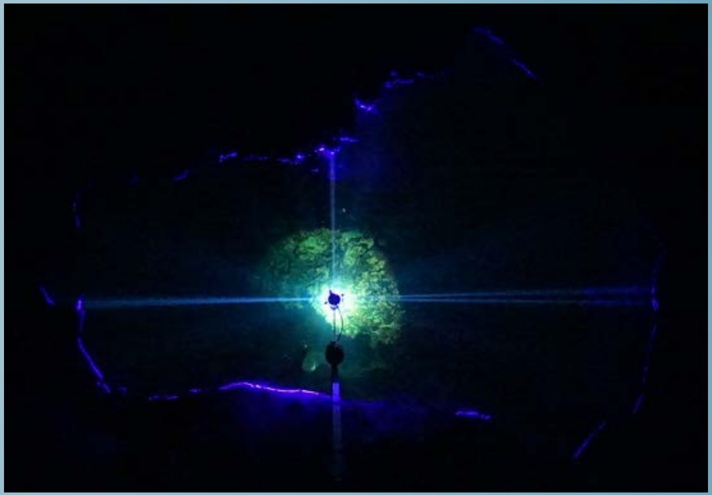
Tulum 2014 - Calibration for B=2m

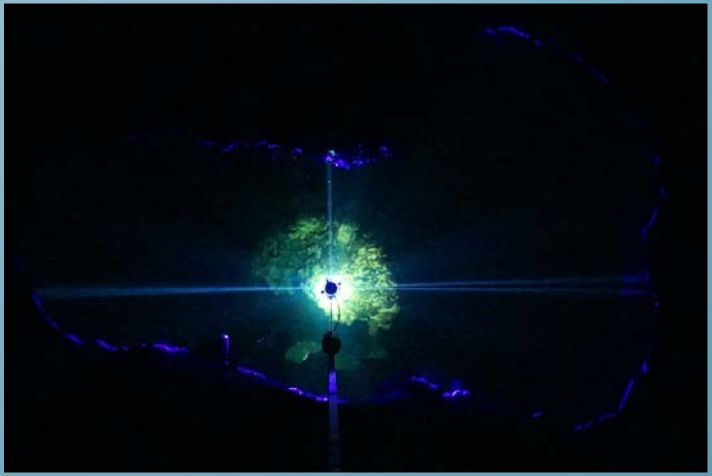




Jailhouse tunnel – single shots

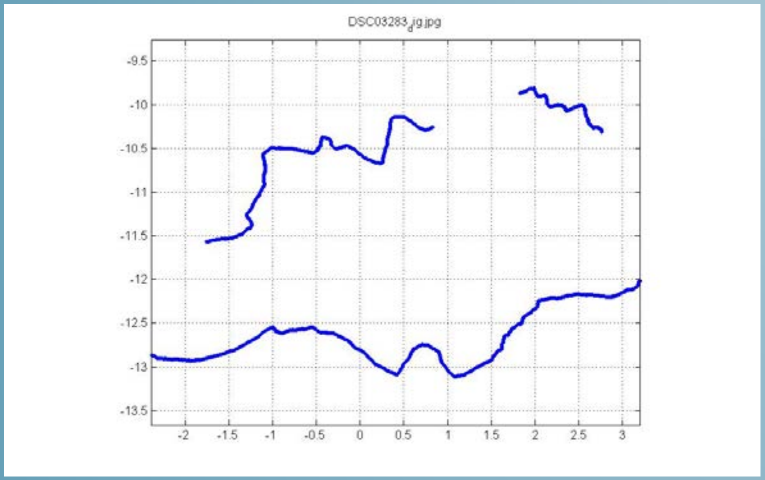
At borehole 2 – looking to borehole 1

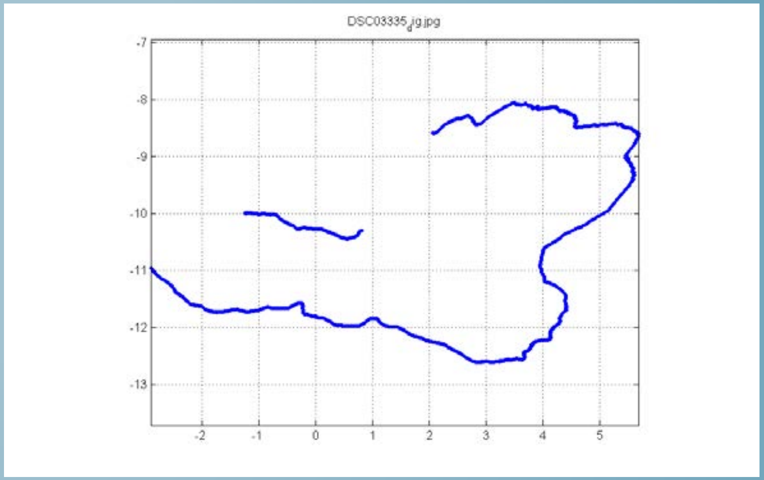


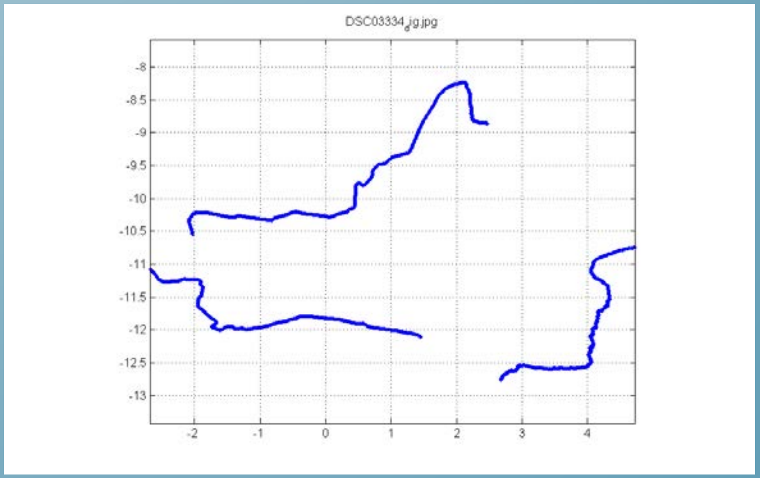


Two last crossections at borehole one

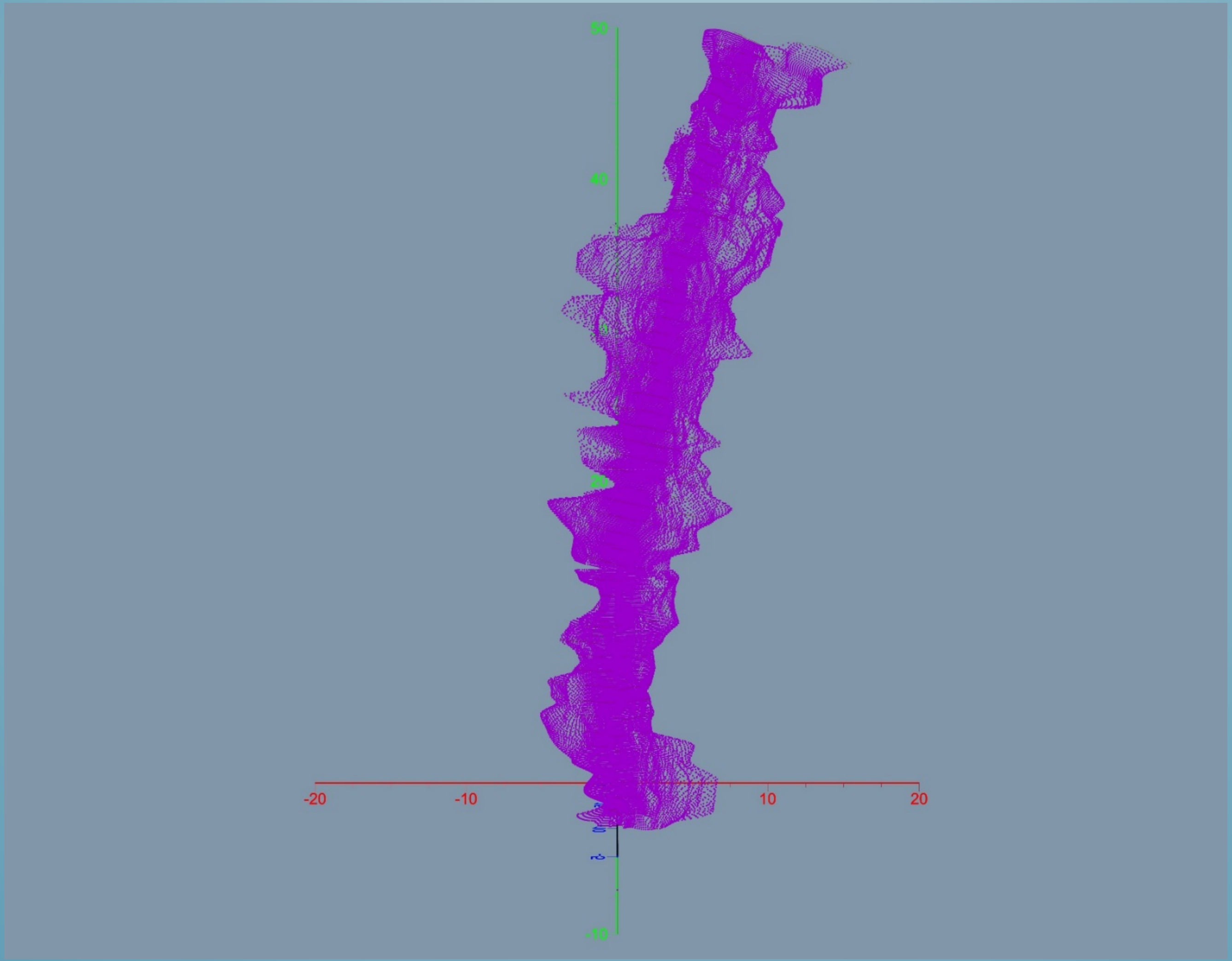
Jailhouse tunnel – single shots mapped







Jailhouse tunnel – interpolated to 0.1 m spacing



3D-model of Jailhouse tunnel

Accuracy of the system

Radial measurement: <1cm for r<2m, < 5cm for r=2 to 10 metres (20m diameter)

Along stick line: < 10 cm without scale line, < 1cm with scale line.

Total accuracy dependends on accuracy of leveling, orientation, and stickline survey.

In plane accuracy decreasing with increasing radius
3d-accuracy decreasing with distance to next fix point

Conclusion

- Fast extensive 3d geometry data acquisition with low cost / low weight system.
- In plane accuracy in mm to cm range depending on spacing and diameter
- Data set represents important input for detailed geometric analysis enabling improved modeling and flux estimation.
- System applicable in dry and underwater caves.
- Measurement environment needs to be dark and clear.

Next Steps:

- Test of radio / magnetic positioning system combined with advanced attitude sensor and inertial measurement unit (IMU).
- Video caption and stereometric image processing.

Gracias!