cGPS for Groundwater Resource Assessment, Hermanus, South Africa

Chris Hartnady [1], Andiswa Mlisa [1], Eric Calais [2] and Richard Wonnacott [3]

[1] Umvoto Africa (Pty) Ltd, Muizenberg, South Africa
[2] EAS Dept, Purdue University, West Lafayette, Indiana, USA
[3] National Geospatial Information Directorate, Mowbray, South Africa

UMVOTO

Outline

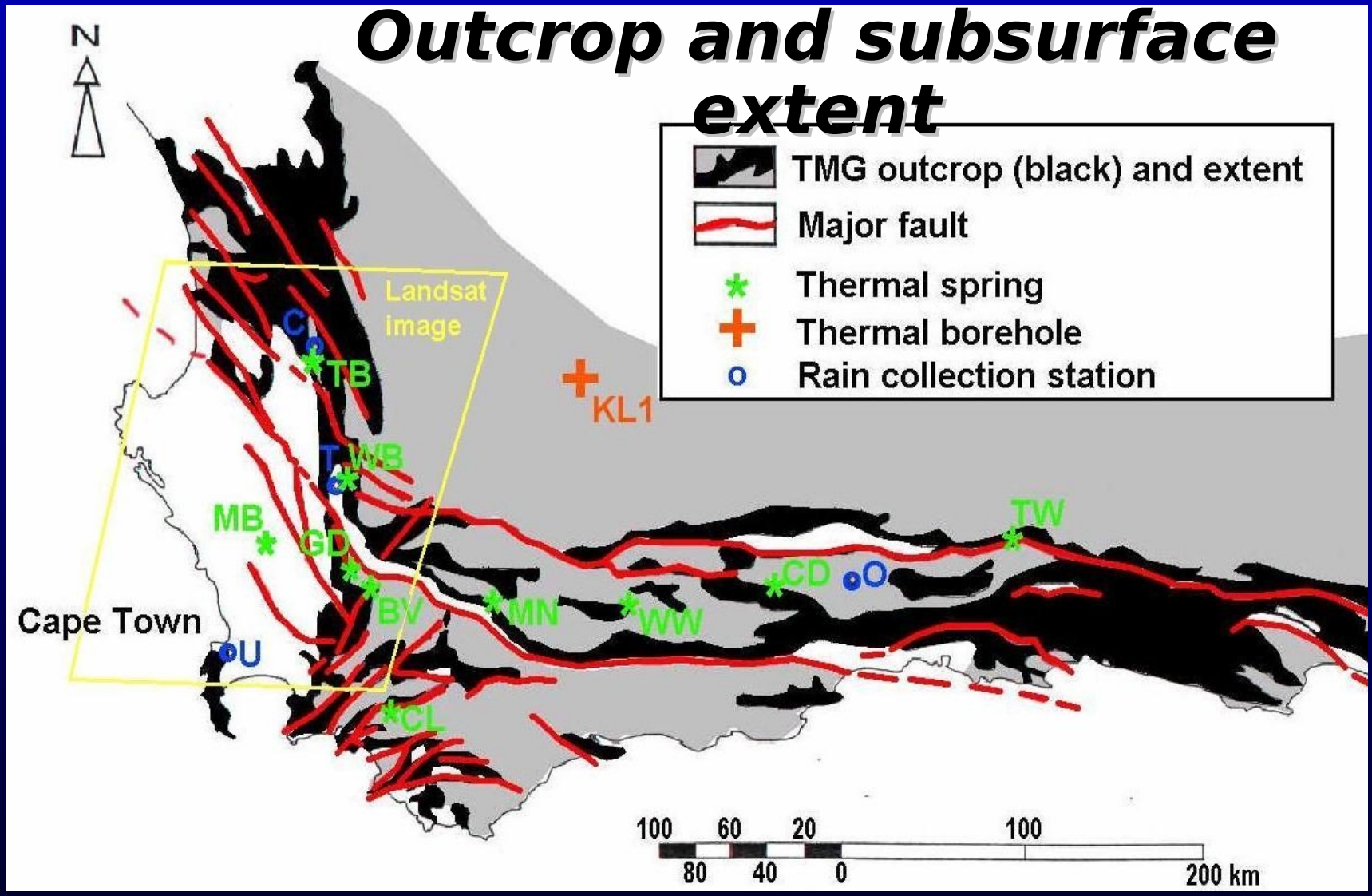
- Table Mountain Group (TMG) hydrogeology
- Gateway wellfield, Hermanus
- Initial results
- Future development?

IGCP 565 contributions

- Support capacity building for South Africa in field of space-geodetic data processing, modeling of hydrological cycle, and interpretation of observations in terms of terrestrial water storage;
- Interpret space-geodetic observations in terms of regional groundwater and soil moisture changes;
- Improve geodetic modeling underpinning processing of observations and extraction of highly accurate information on changes in terrestrial water storage;
- Promote practical use of products for regional water management through interaction with water management authorities, particularly in developing countries of Africa

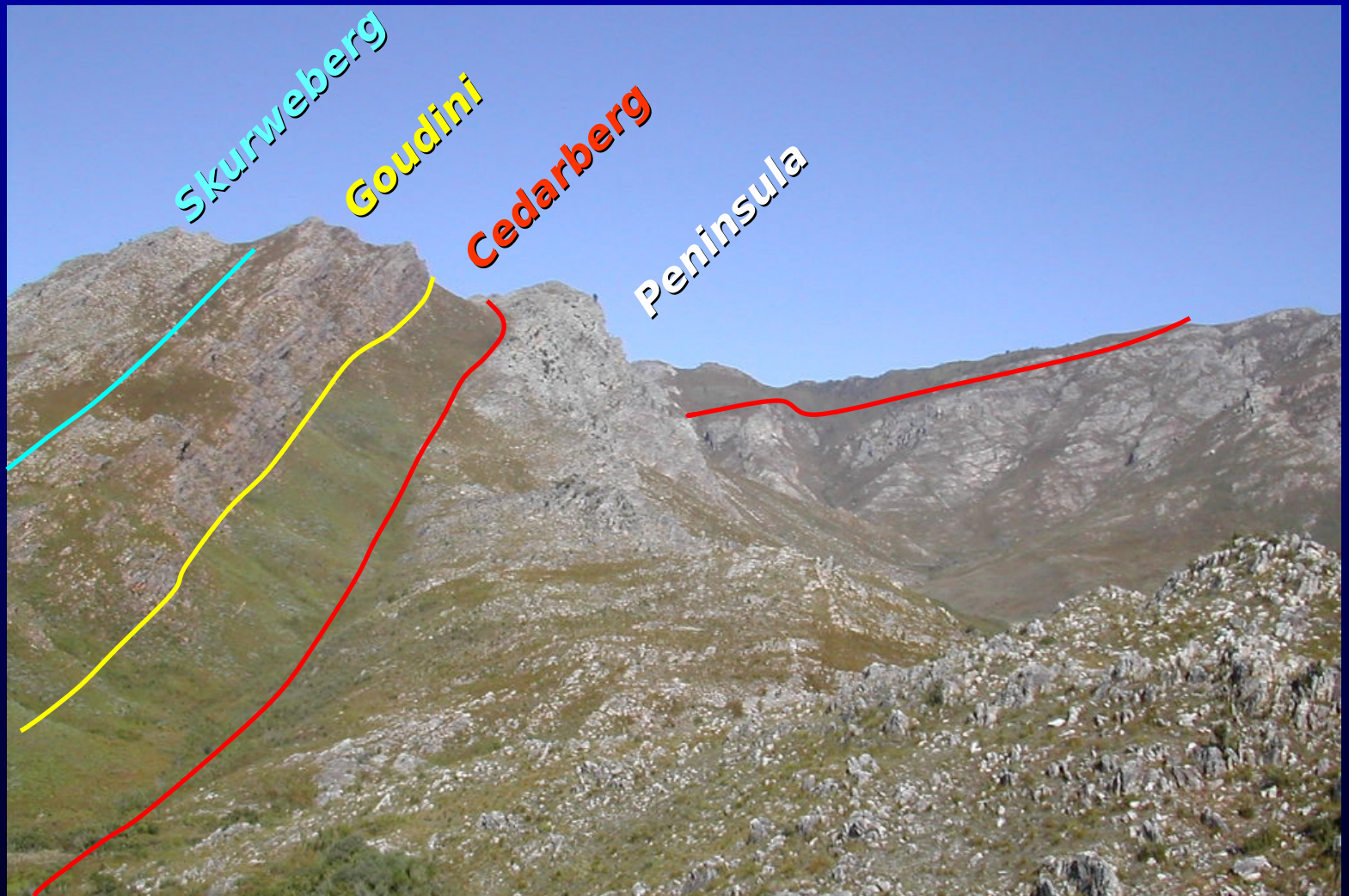
Table Mountain Group (TMG) hydrogeology

Table Mountain Group



TMG Stratigraphy

Cedarberg view



TMG Hydrostratigraphy

Table 1

Coincident hydrostratigraphic units of western TMG

Superunits	Units	Subunits
Bokkeveld	Gydo Mega-aquitard	
Table Mountain Superaquifer	Nardouw Aquifer	De Doorns Subaquifer
		Verlorenvalley Mini-aquitard
		Skurweberg Subaquifer
	Winterhoek Mega-aquitard	Goudini Meso-aquitard
		Cedarberg Meso-aquitard
		Pakhuis Mini-aquitard
	Peninsula Aquifer	Platteklip Subaquifer
		Leeukop Subaquifer
	Graafwater Meso-aquitard	-
	Piekenierskloof Aquifer	(not yet identified)
Saldanian	Basement aquicludes	

Palaeozoic (Ordovician-Silurian) aquifers and aquitards

Late-Ordovician

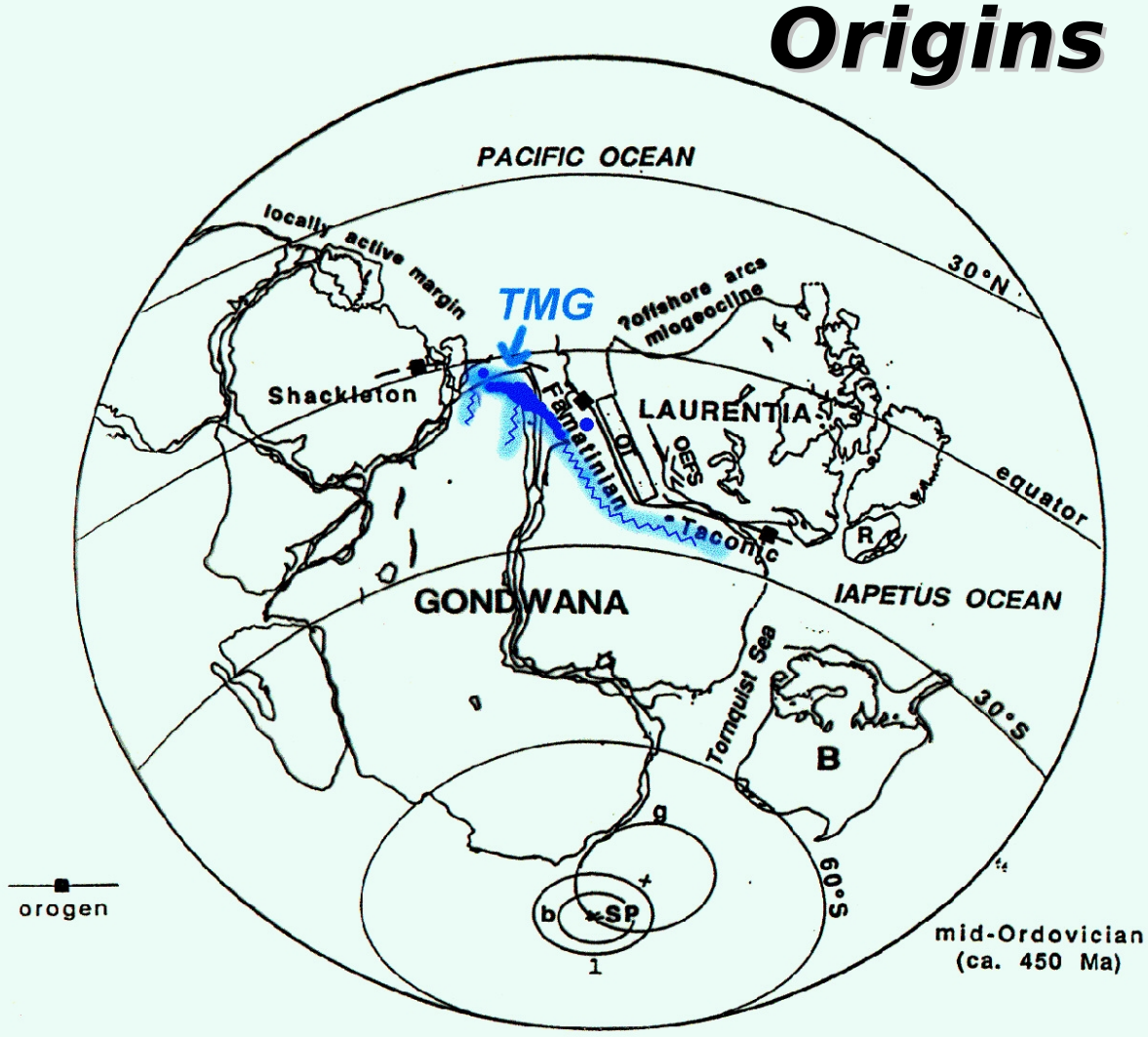
Mass Extinction

Amazon delta analogue

But no land plants in Ordovician!

TMG Palaeogeography

Deposition of TMG at mouth of Amazon-scale river system draining southern front of vast Famatinian-Taconic mountain belt in collision zone between Gondwana and Laurentia

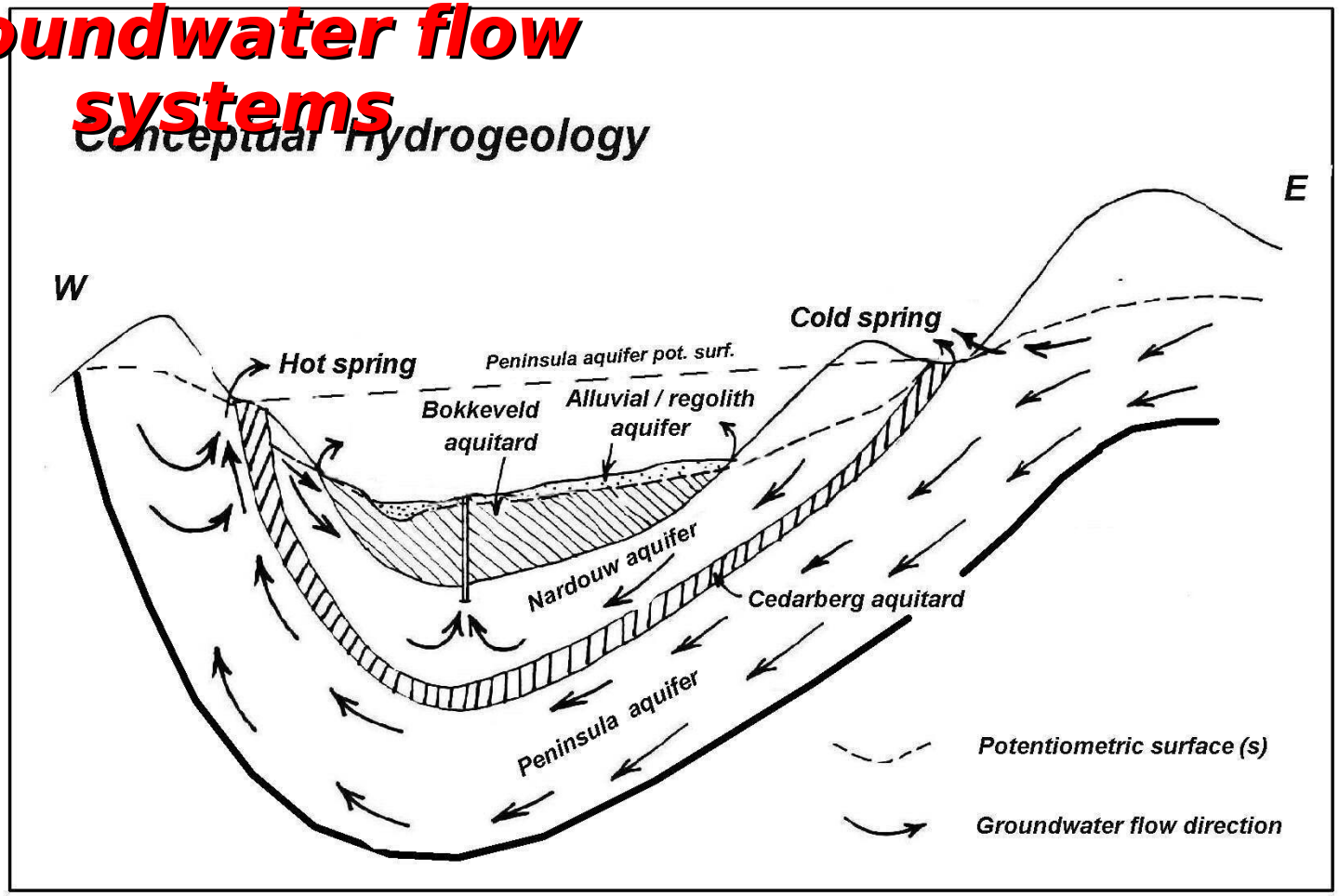


TMG groundwater

- Fractured quartzitic aquifer of immense thickness and wide areal extent
- Underlies scenic mountainous topography
  - Controls orographic precipitation (rainfall/ snow) patterns with strong gradients and seasonality
  - Supports an exceptionally diverse mountain biome within the unique Cape Floral Kingdom (“fynbos”)
- Major groundwater resource potential and unique natural setting for study of fluid migration and storage in geochemically

TMG regional flow systems

Thermal springs and deep groundwater flow systems



TMG deep groundwater

Fluid Flow in Fractured Rock

Fracture Porosity and Fluid Pressure

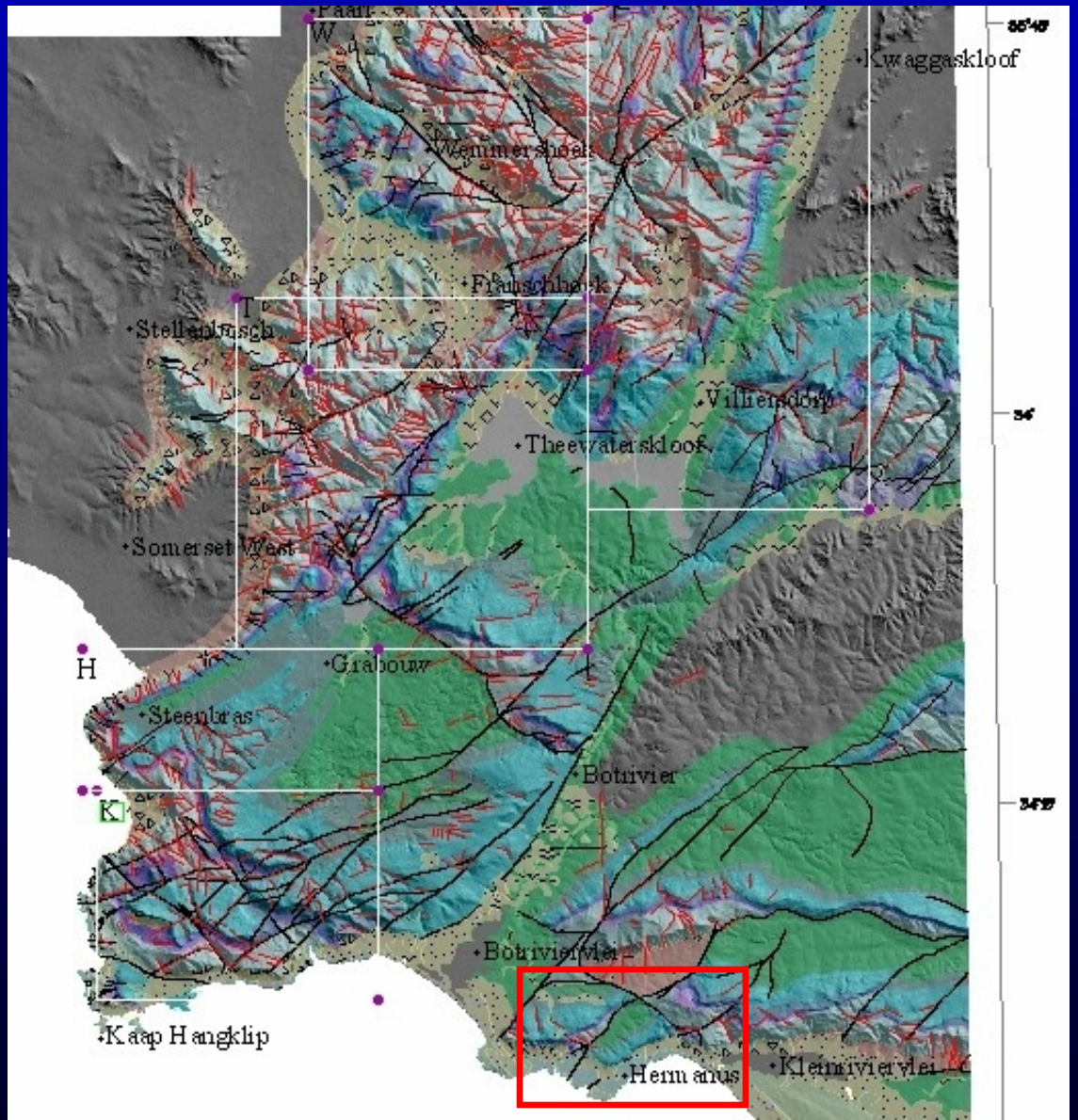
'The in-situ porosity and permeability of fractured rocks are generally considered to be a function of fluid pressure … (there is) abundant evidence that fractures "breathe", or open and close in response to changes in fluid pressure. As there is a direct relationship between fluid pressure and aperture opening (and, consequently, permeability) there follows some relationship between fracture strength,

Deep groundwater studies

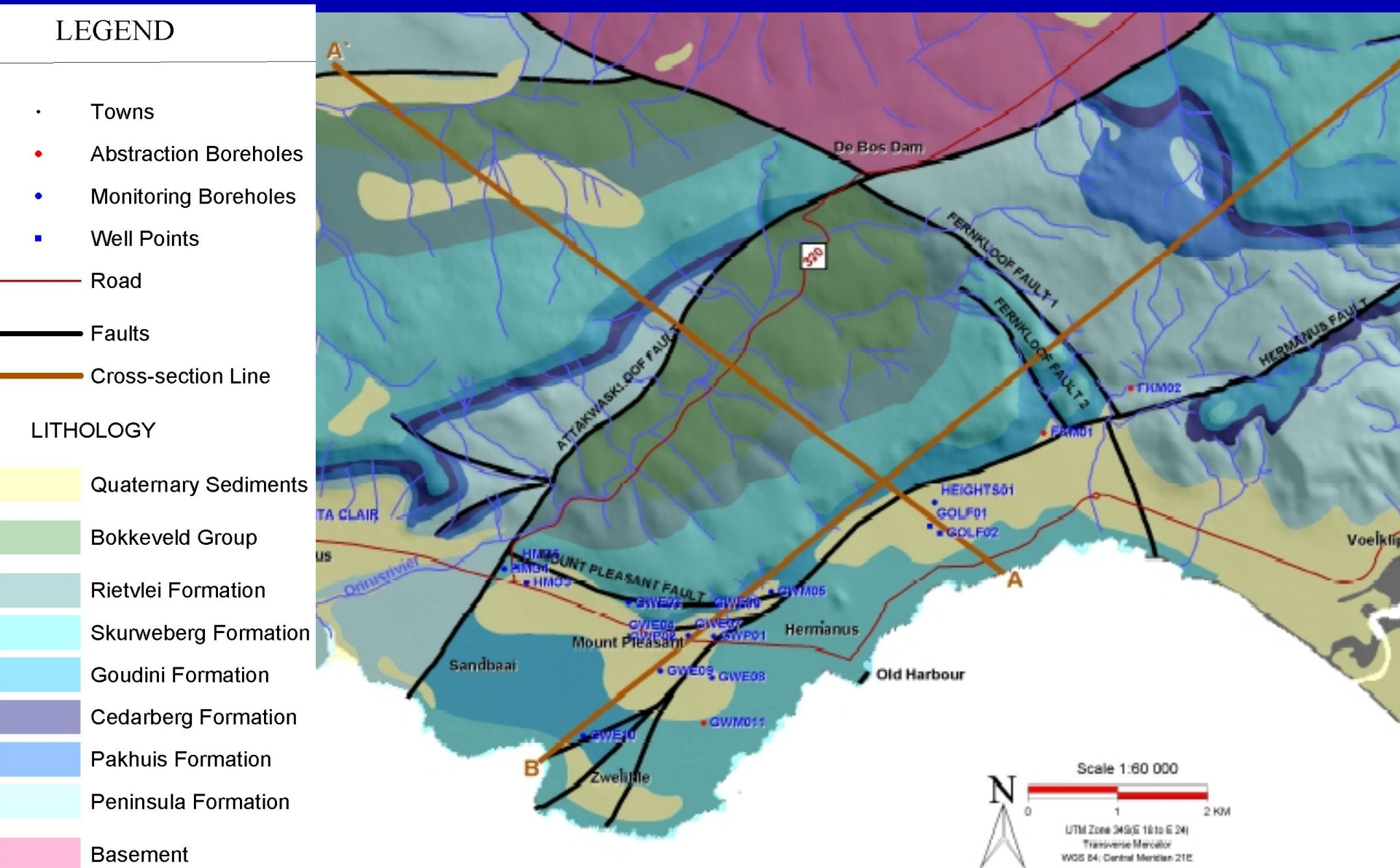
Cape Fold Belt context

Gateway wellfield, Hermanus

Digital geology-topography

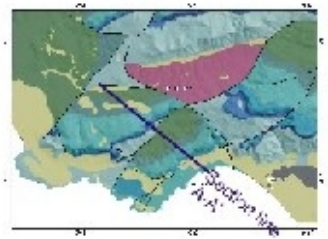


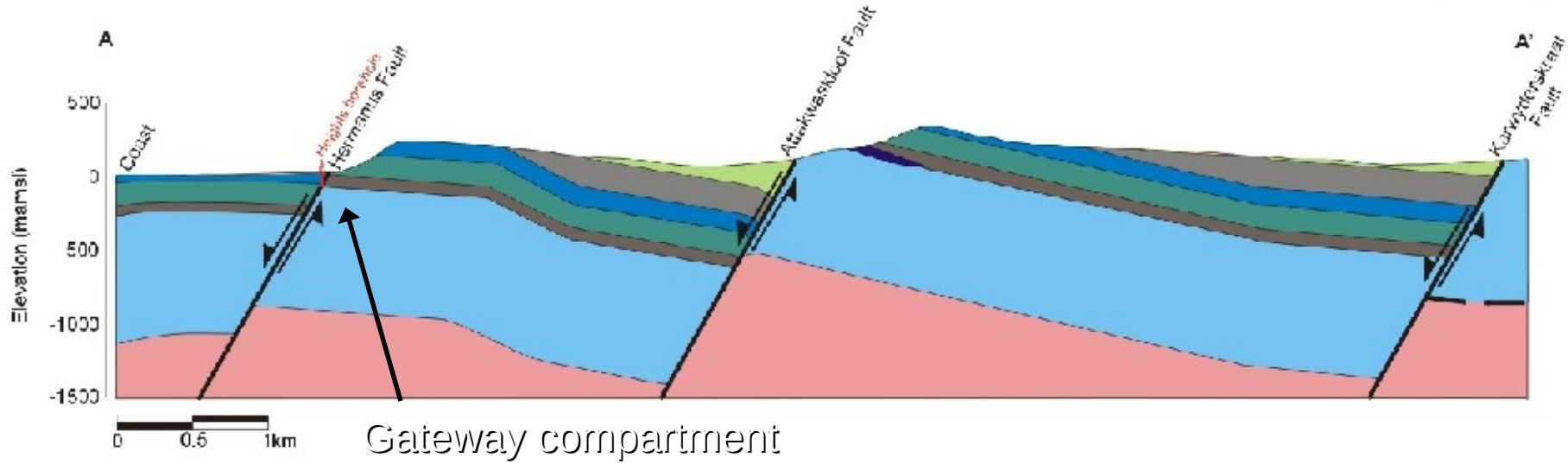
Hermanus Geological Setting



Geological profile

Gateway wellfield in confined Peninsula Formation between Hermanus and Attakwaskloof faults





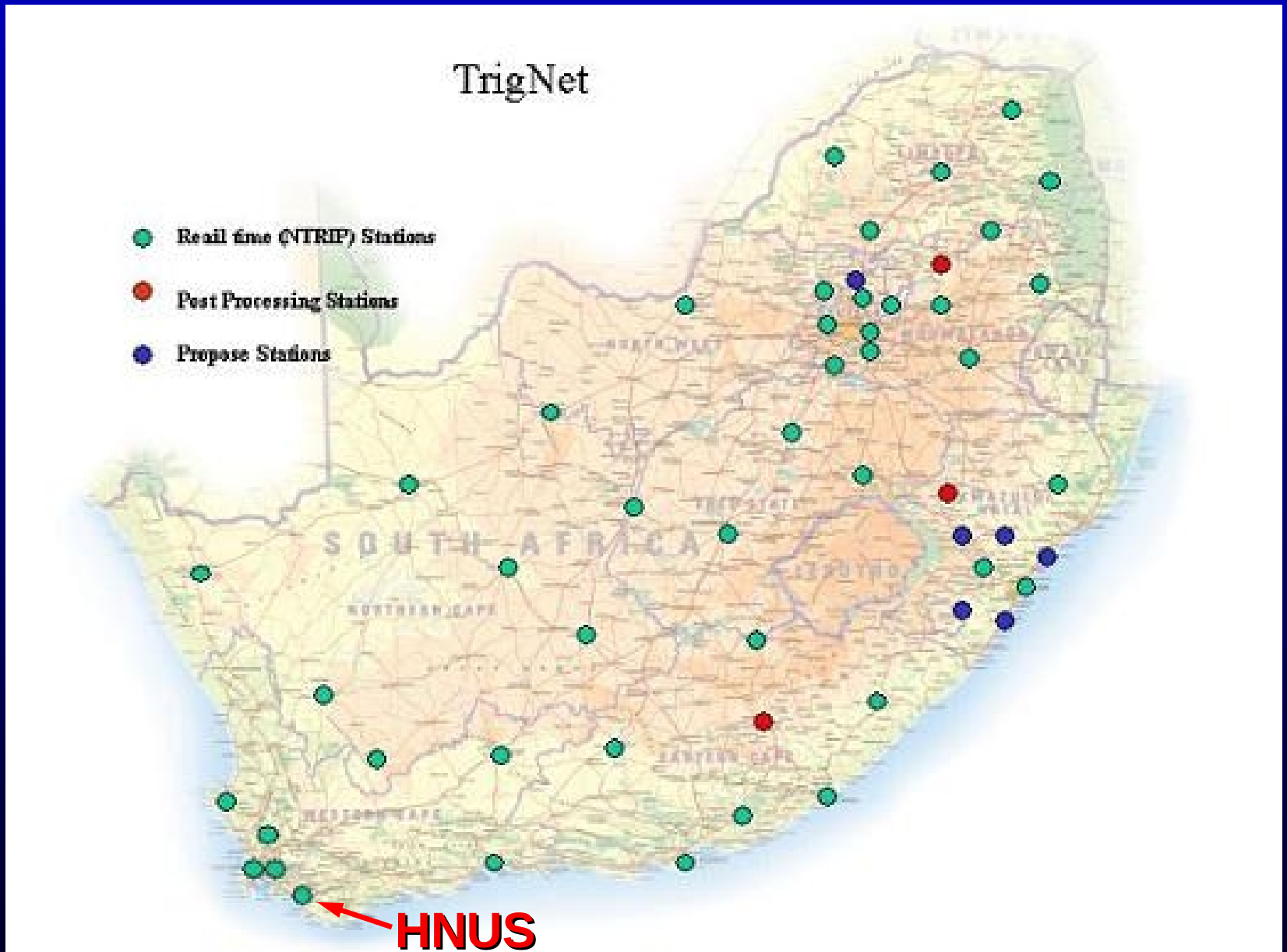
Gateway compartment

Gateway wellfield and HMO

South African TrigNet system

- Network of permanent continuously operating GPS (cGPS) base stations
- Distributed throughout South Africa at approximately 200 – 300 km spacing
- All stations record 1-second epoch data on both GPS frequencies (L1 and L2) through geodetic-standard choke ring antennas
- 21 stations stream data continuously to TrigNet control centre in National Geospatial Information Directorate
- Available within 30 minutes after each hour for 24 hours a day

TrigNet station distribution



Receiver and comms unit

- Ashtech receiver
- E-Box

Antenna & signal acquisition

- Trimble

Instrument challenges

- Getting recycled receivers to work with new antennae
- Connecting receivers to i-box / e-box
- Installing software in e-box
  - No CD/DVD drive
  - Windows embedded

Construction and establishment

- Pillar to be
  - rigid
  - firmly anchored to borehole plinth

Security issues

- Locked box & fencing

cGPS at Gateway wellfield

- Water Research Commission - R&D : Umvoto, CDSM and Purdue University, USA
- Monument and antenna installation at wellheads (Nov 2008) for measurement of surface subsidence during groundwater abstraction

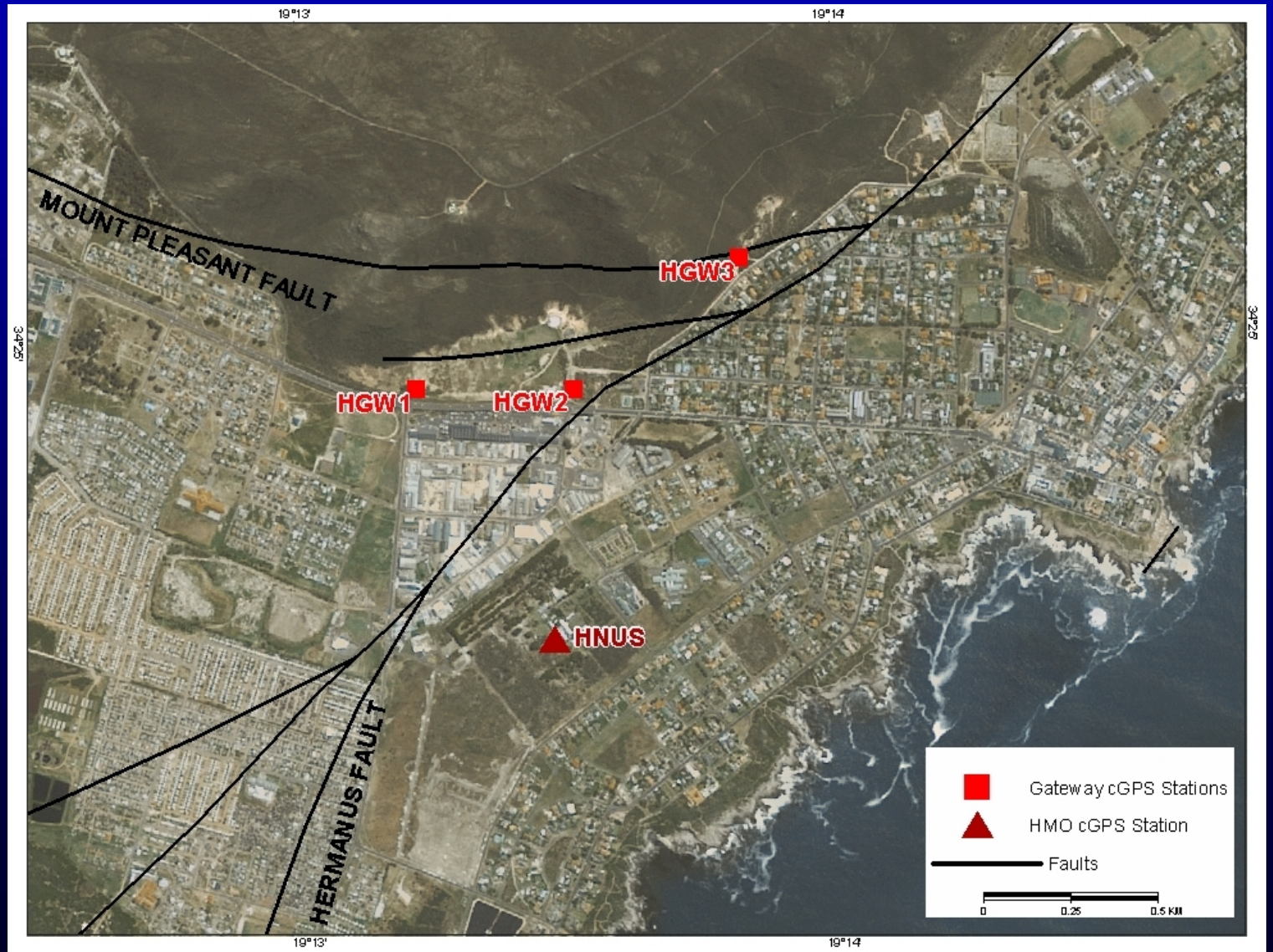
Provides practical new approach to measuring compressibility parameters for confined aquifer storage, modelling storage fluctuations

Initial results

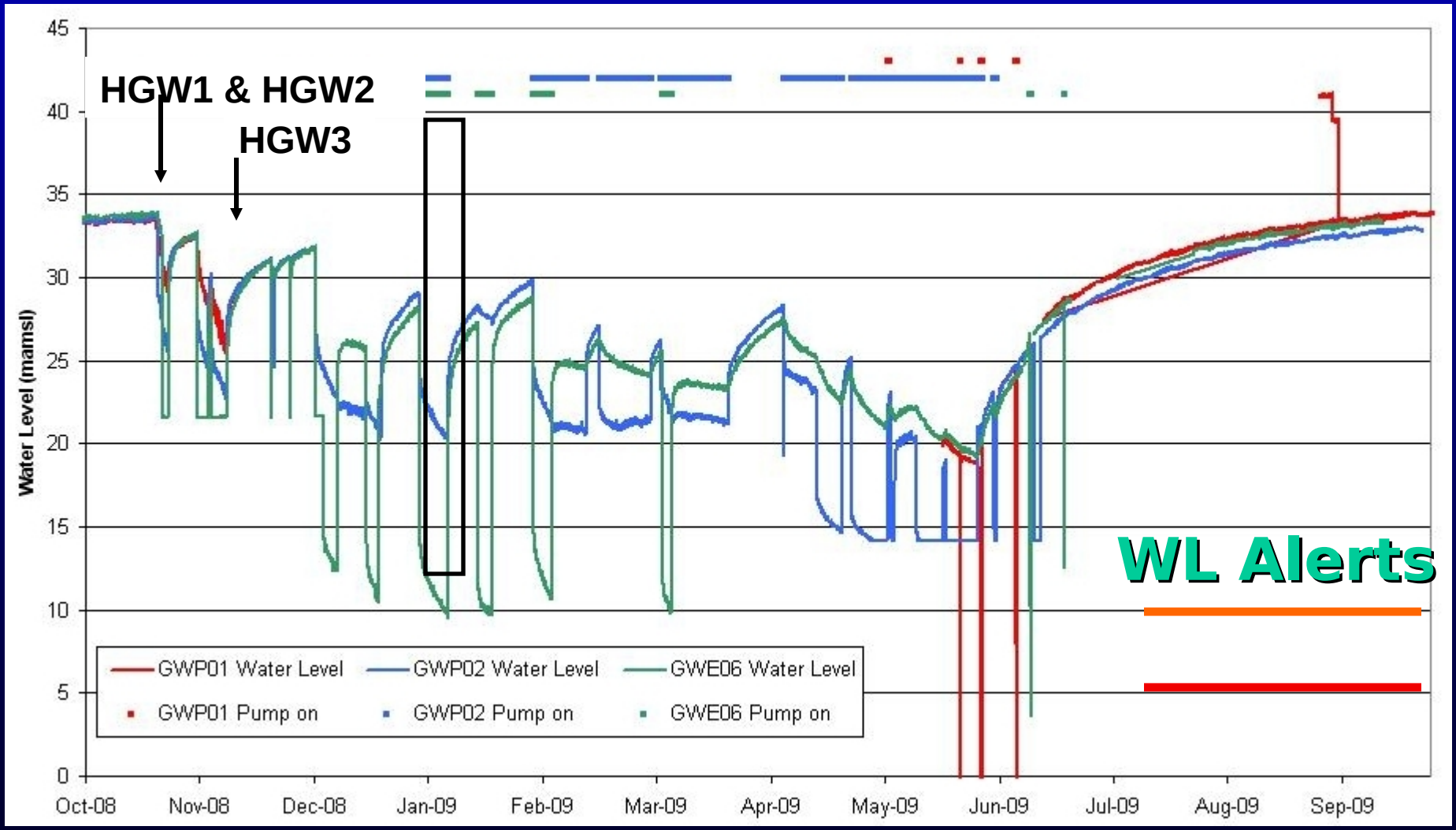
Hydro-monitoring components

- Water-level in fractured-rock aquifer
- Water-level in primary alluvial aquifer
- Water quality in fractured-rock aquifer
- Spring & surface-water flow rate and quality
- Rainfall, atmospheric temperature

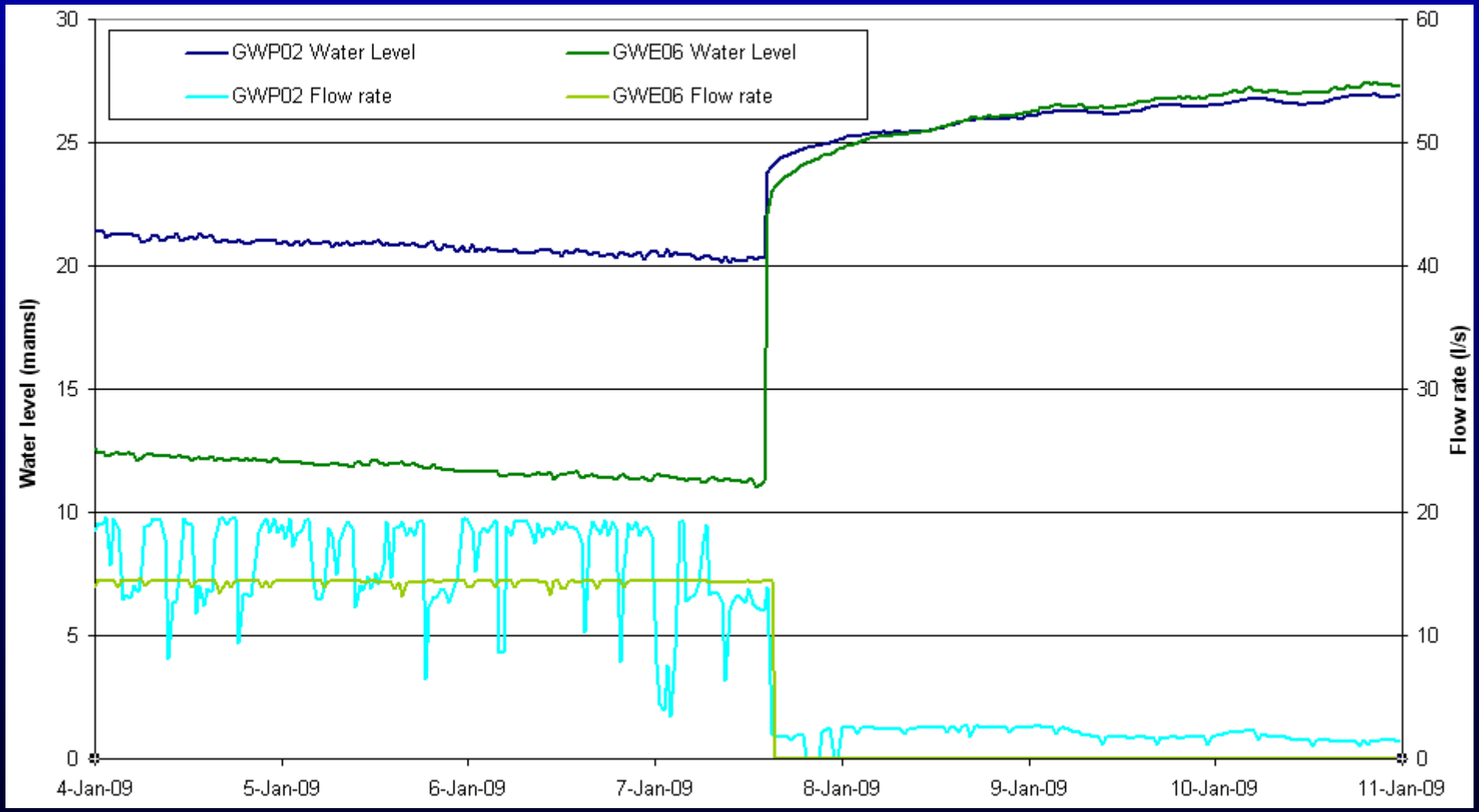
Gateway and HMO cGPS



HY 2008-09 Test Pumping



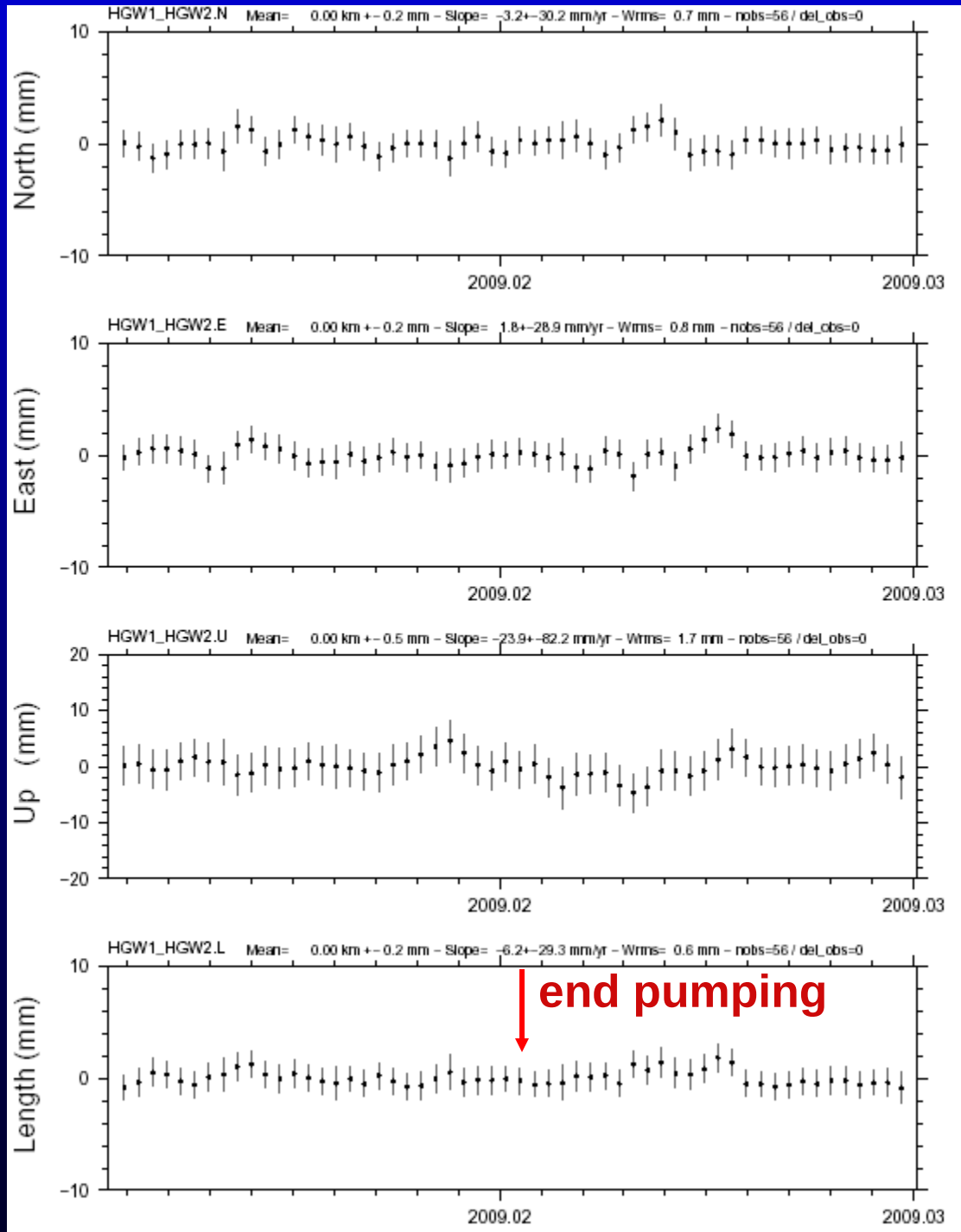
Pumping switch-off observations



HGW1-HGW2 Results

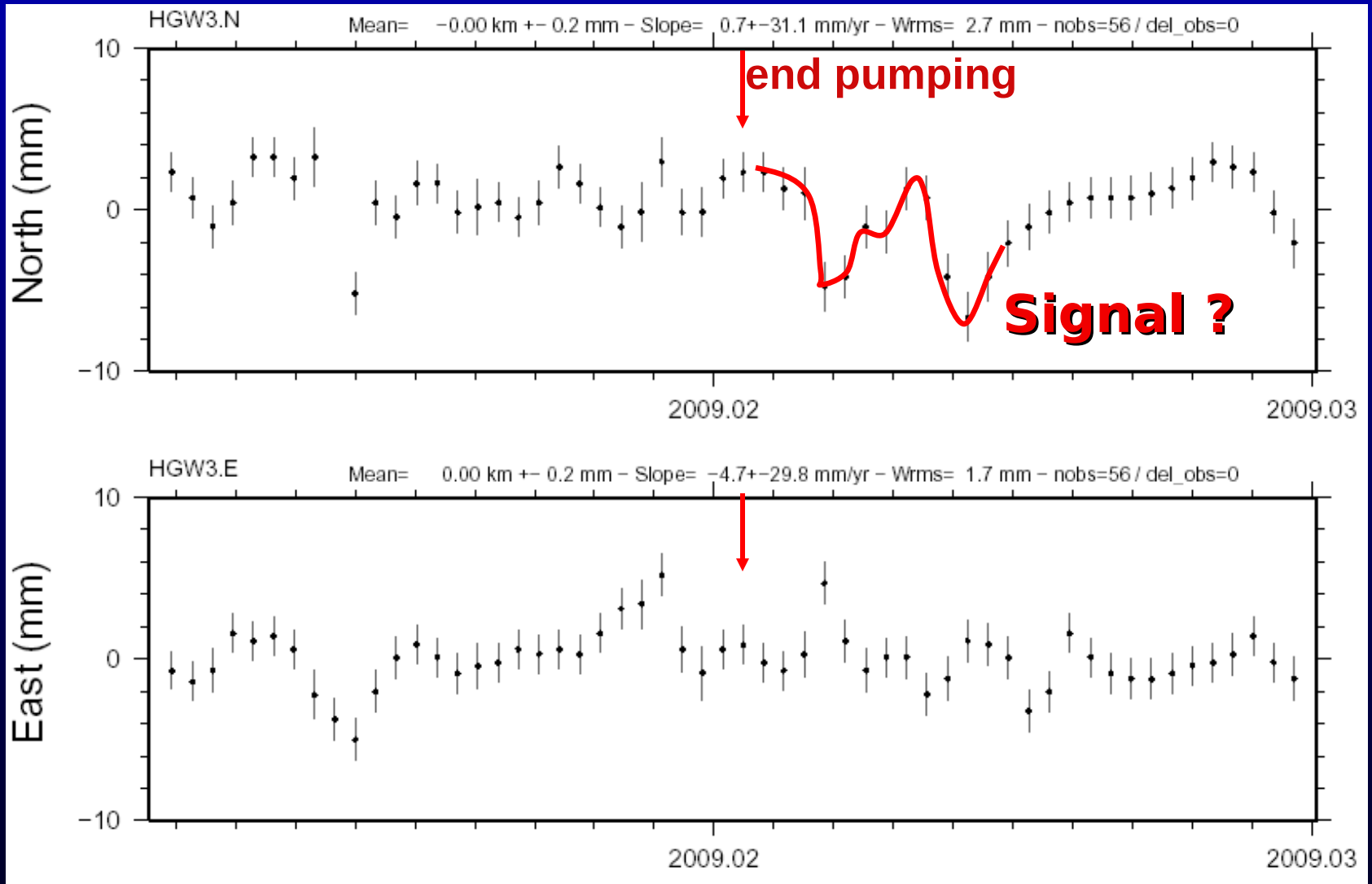
- Distance between GWP02 pumping borehole & GWP01 (bottom panel) remains unchanged

- No clear signal associated with simultaneous pumping switch-off at GWP02 and GWE06



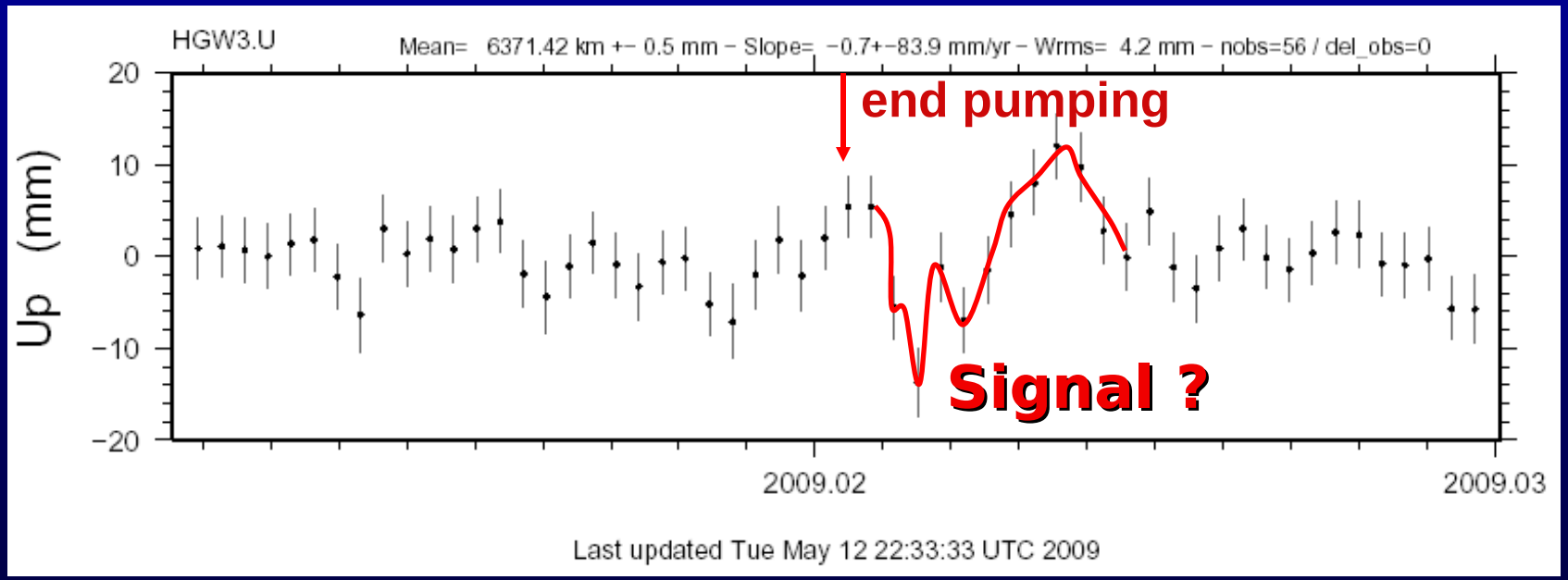
HGW3 Result

Horizontal motion of GWE06 relative to HNUS



HGW3 results

Vertical motion relative to HNUS



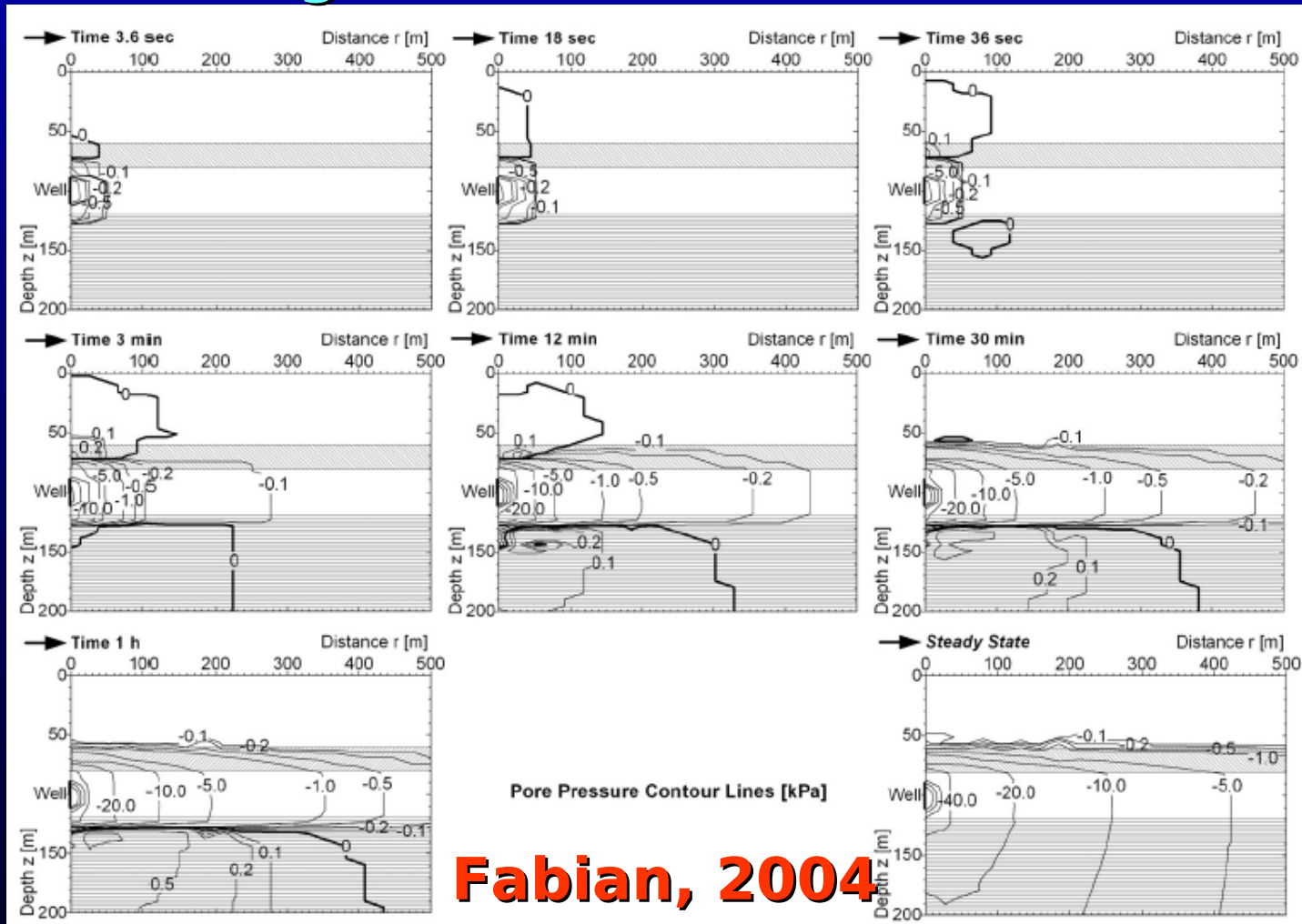
NB Drawdown limitation to <25-30 m because of seawater intrusion hazard may mean weak signal

Interpretation issue

Jacob model (1D) oversimplifies

“Noordbergum effect” shown

- Need to account for 3D deformation and stress transients in layered aquifer-aquitard system

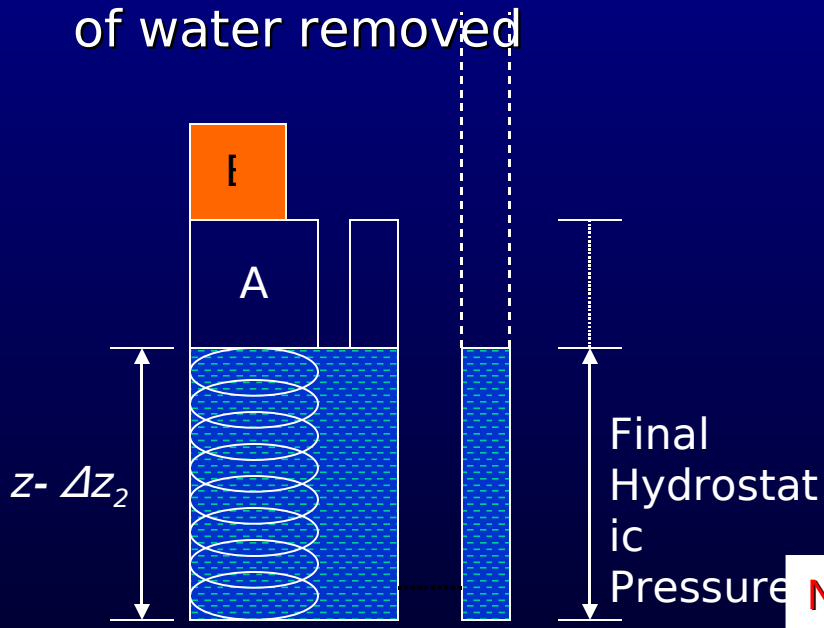


Fabian, 2004

Future development?

Confined aquifer compressibility

- System reaches equilibrium
- Compressed spring reflects added Load B
- Drop in hydrostatic pressure indicates level of water removed



Classic Jacob Relation (assuming solely vertical strain in aquifer)

$$S_s = \rho_w g (\beta_p + n \beta_w)$$

S_s = Specific Storage (m^{-1})

ρ_w = mass density of water ($kg\ m^{-3}$)

g = gravitational acceleration ($m\ s^{-2}$)

β_p = skeletal compressibility of aquifer matrix (Pa^{-1})

β_w = compressibility of water (Pa^{-1})

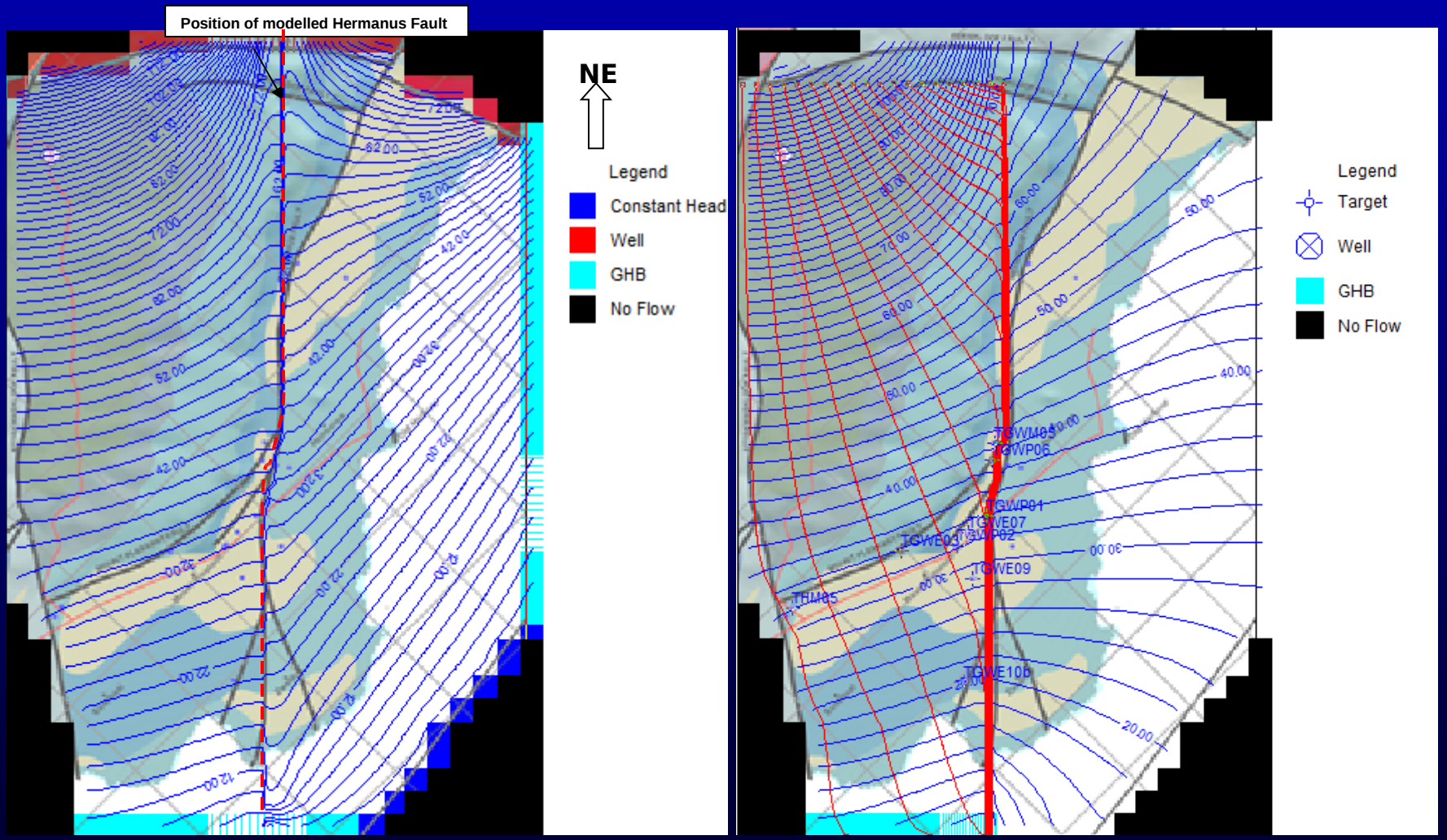
n = effective porosity

Water Cylinder = Aquifer Storage

NB: S_s component due to pore compressibility does not involve porosity

Plug = Borehole

Gateway steady-state model

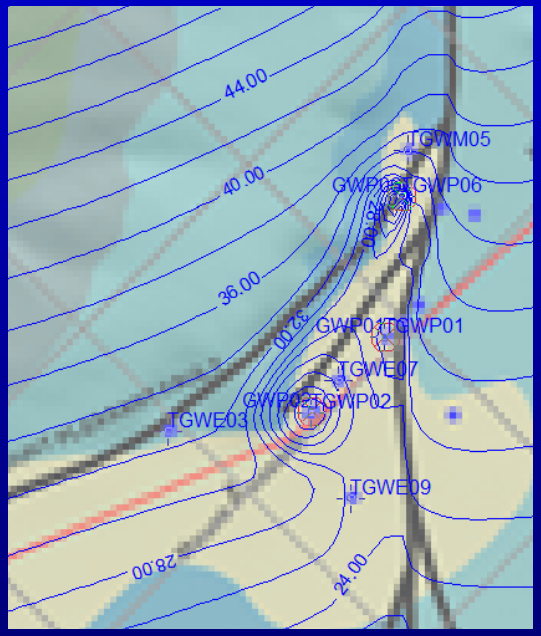


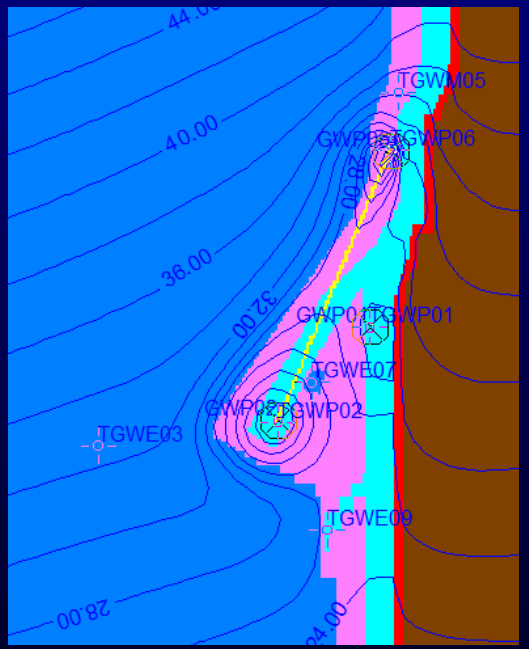
Alice Dodman, 2008

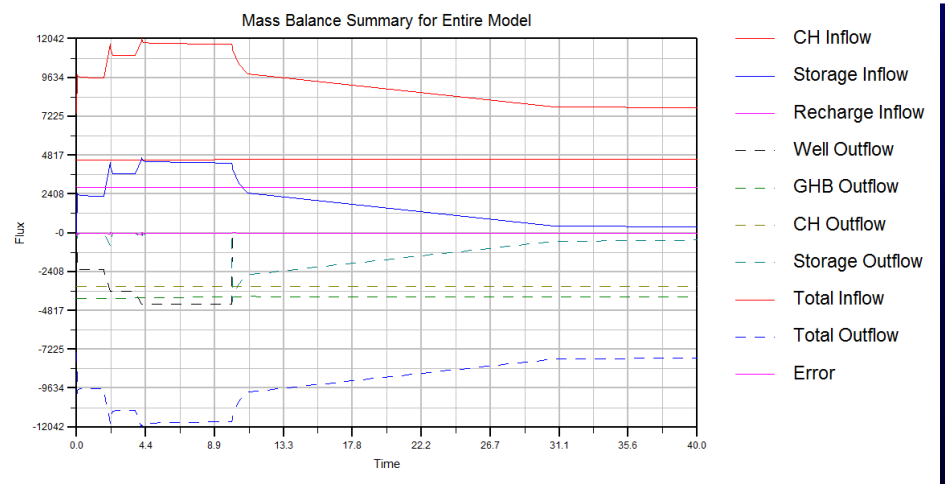
Transient model

Set-up: - calibrated using 2005 pump test
- recharge boundary converted to CH boundary to assess impact of abstraction

Results: - No modelled drawdown in Skurweberg
- Interference between production boreholes
- GWE06 and GWE02 connected by high K fault (in early simulations modelled drawdown in abstraction borehole GWE06 underestimated by approximately 20 m)
- Mass balance indicates CH inflow ~ constant



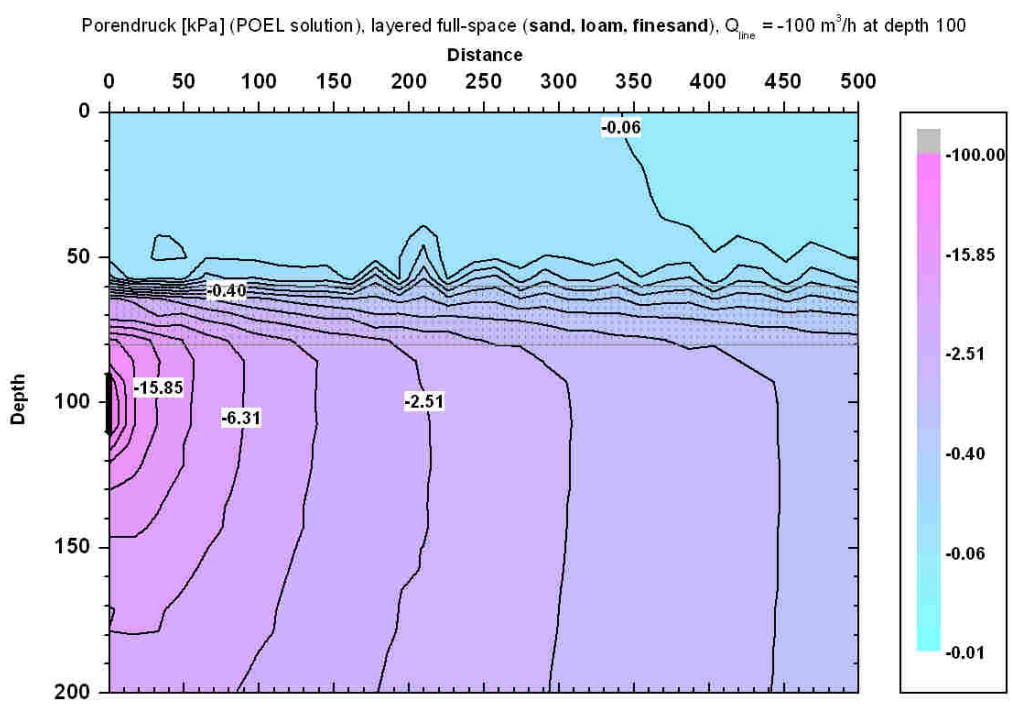




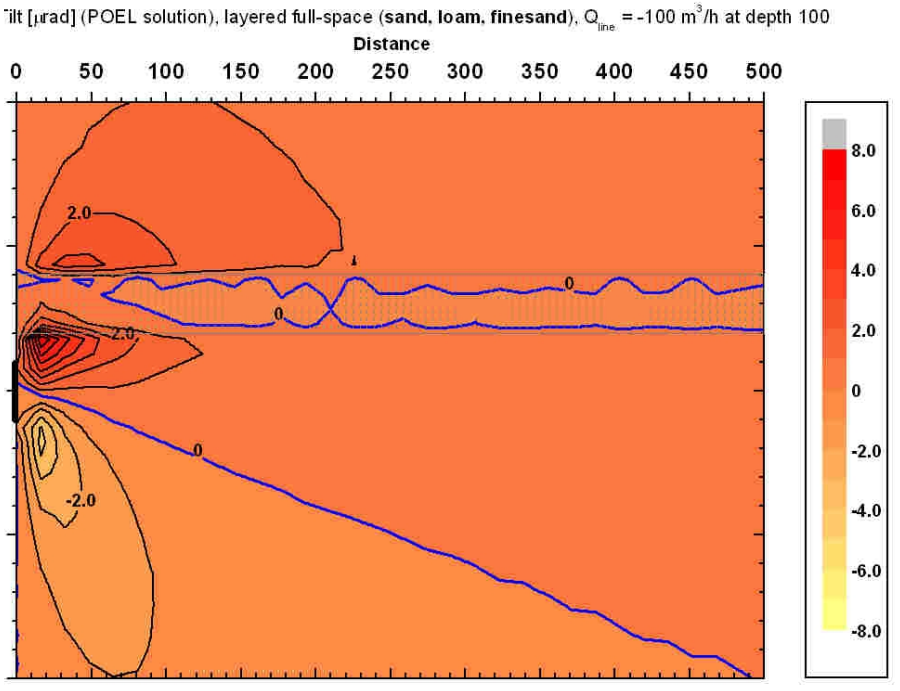
Poroelastic modelling

- Combined solutions (2d) for pressure head and tilt in layered half-space using POEL code
  - from Fabian, 2004

Pressure (kPa)

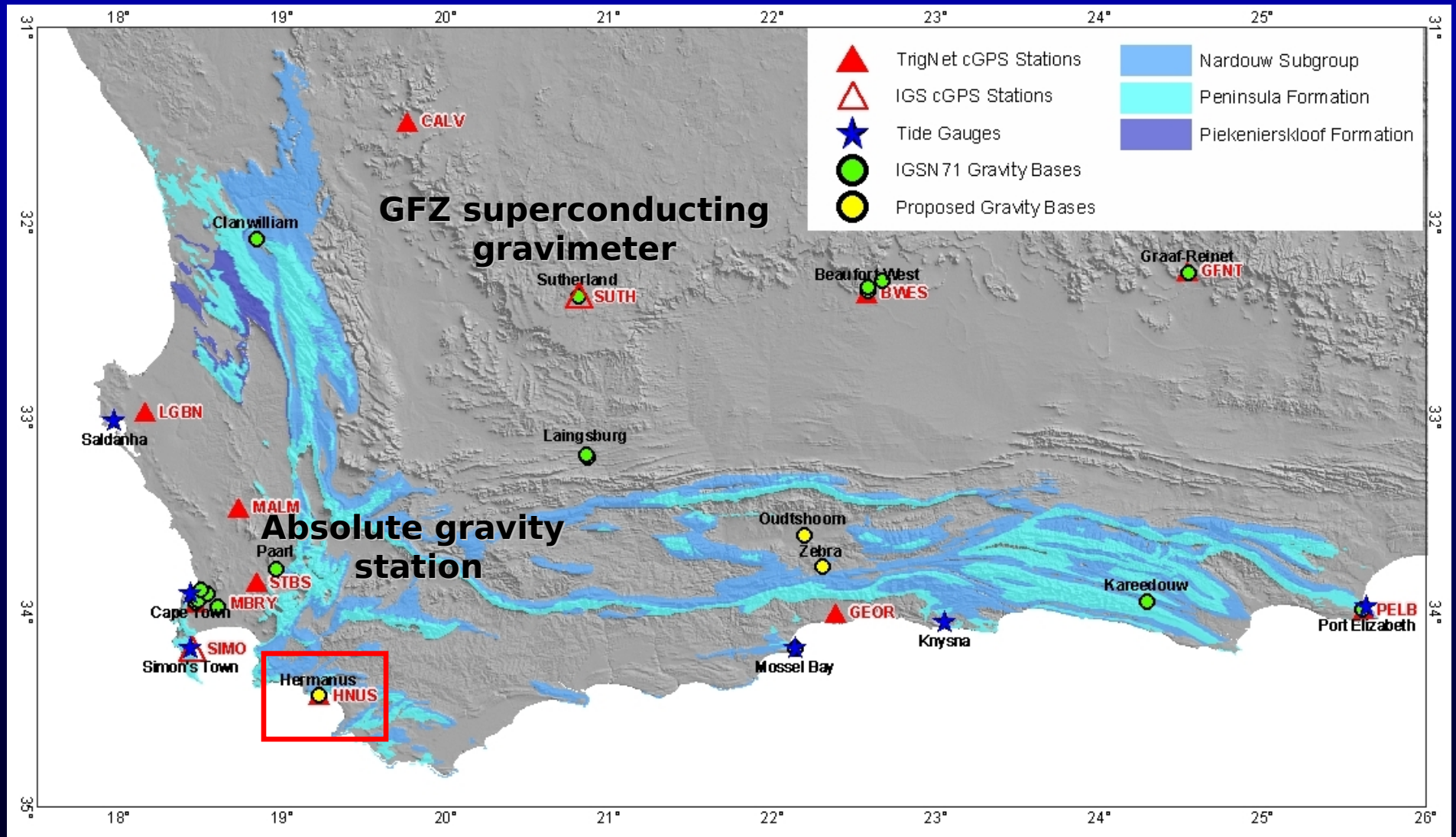


Tilt (µrad)



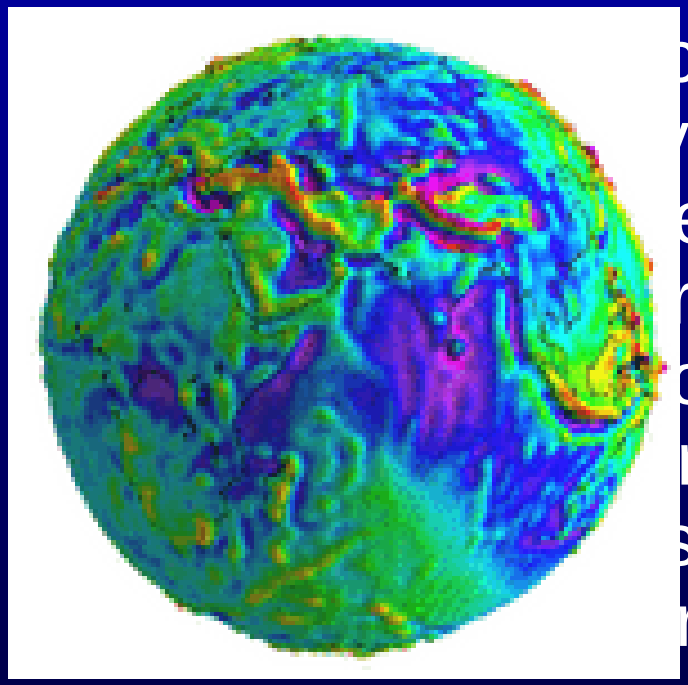
S Cape geodetic framework

Conjunctive cGPS and gravity monitoring?



GRACE

- ***G***ravity ***R***ecovery ***A***nd ***C***limate ***E***xperiment satellite mission – co-PI: Byron Tapley (UT Austin)



card is its ability to measure the

es

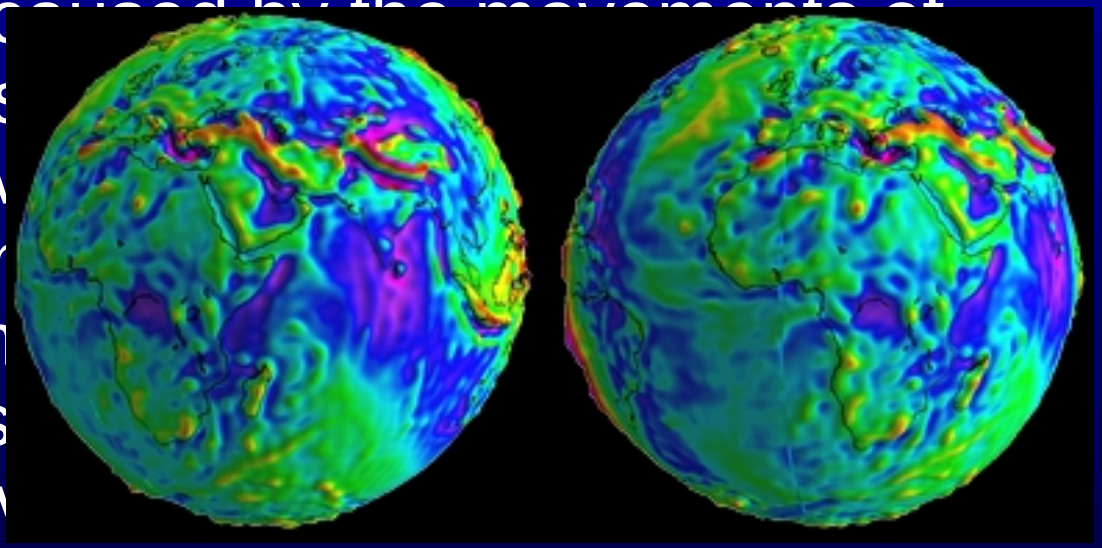
riv

or

m

ss

riv



  - "Eventually," says Tapley, "we will be able to let countries in Africa know how their aquifers are changing".

National Geogaphic Magazine quote

Mesquite, Nevada case study

- Comparisons with Hermanus?

ELSEVIER

Journal of Hydrology xx (2005) 1–20

Journal of Hydrology

www.elsevier.com/locate/jhydrol

Three-dimensional deformation and strain induced by municipal pumping, part 1: Analysis of field data

Thomas J. Burbey[a,*], Sandy M. Warner[b,1], Geoff Blewitt[c,2], John W. Bell[c,3], Emma Hill[b,4]

[a]*Department of Geosciences Virginia Tech 4044 Derring Hall Blacksburg, VA 24061, USA*
[b]*Olver Incorporated 1116 South Main St., Suite 100 Blacksburg, VA 24060, USA*
[c]*Nevada Bureau of Mines and Geology University of Nevada, Reno Mail Stop 178 Reno, NV 89557, USA*

Received 12 October 2004; revised 7 June 2005; accepted 13 June 2005

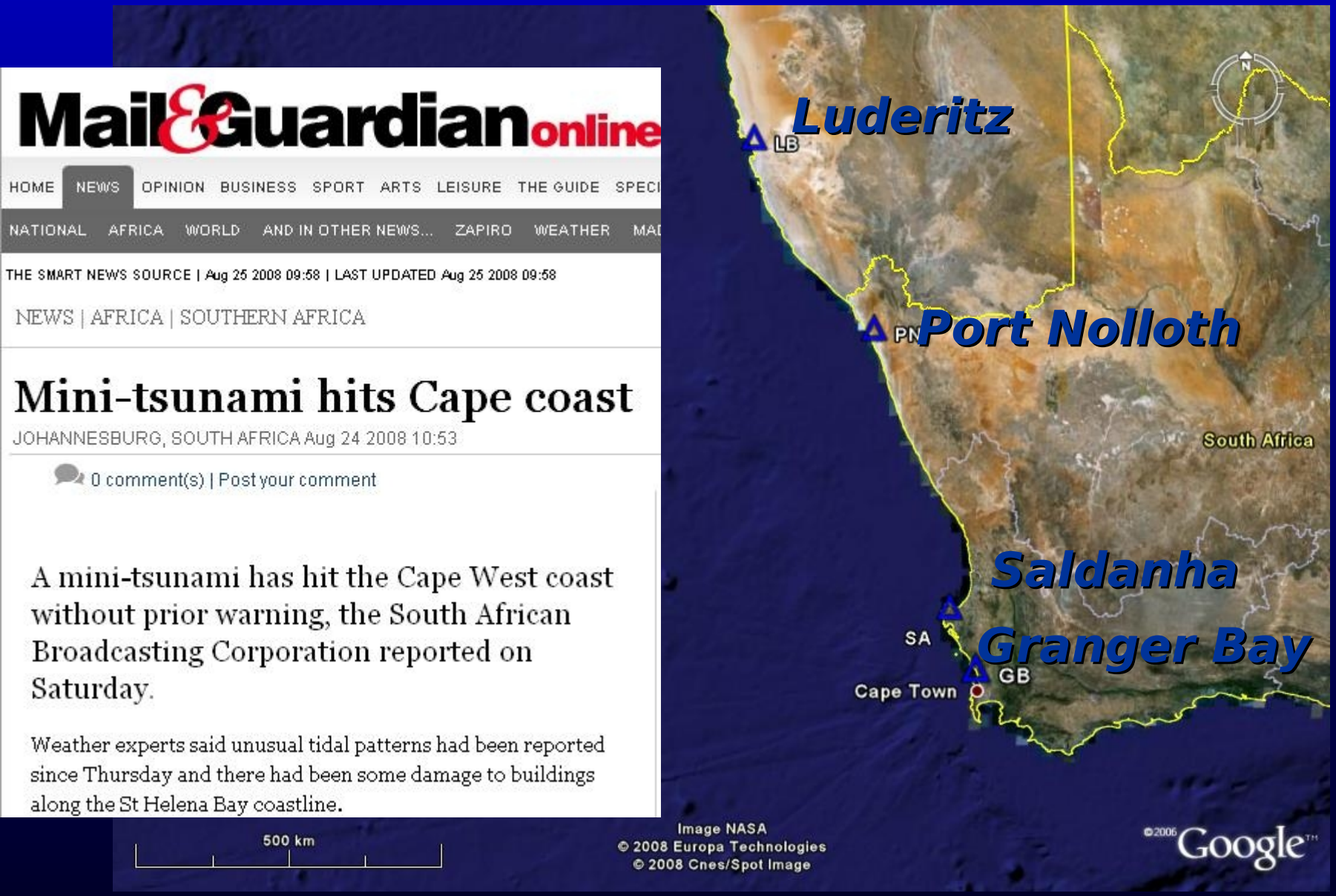
Acknowledgements

- Overstrand Municipality, in particular town engineer, Mr Stephen Muller, for co-operation
- WRC and Dr Shafiek Adams for funding support
- Department of Land Affairs (National Geospatial Information Directorate) for technical support and assistance related to TrigNet and additional GPS hardware

UMVOTO

HNUS
&
W Coast (meteo-)tsunami study

Tide gauges on Cape West Coast



Mail&Guardian online

HOME | NEWS | OPINION | BUSINESS | SPORT | ARTS | LEISURE | THE GUIDE | SPECI

NATIONAL | AFRICA | WORLD | AND IN OTHER NEWS... | ZAPIRO | WEATHER | MA

THE SMART NEWS SOURCE | Aug 25 2008 09:58 | LAST UPDATED Aug 25 2008 09:58

NEWS | AFRICA | SOUTHERN AFRICA

Mini-tsunami hits Cape coast

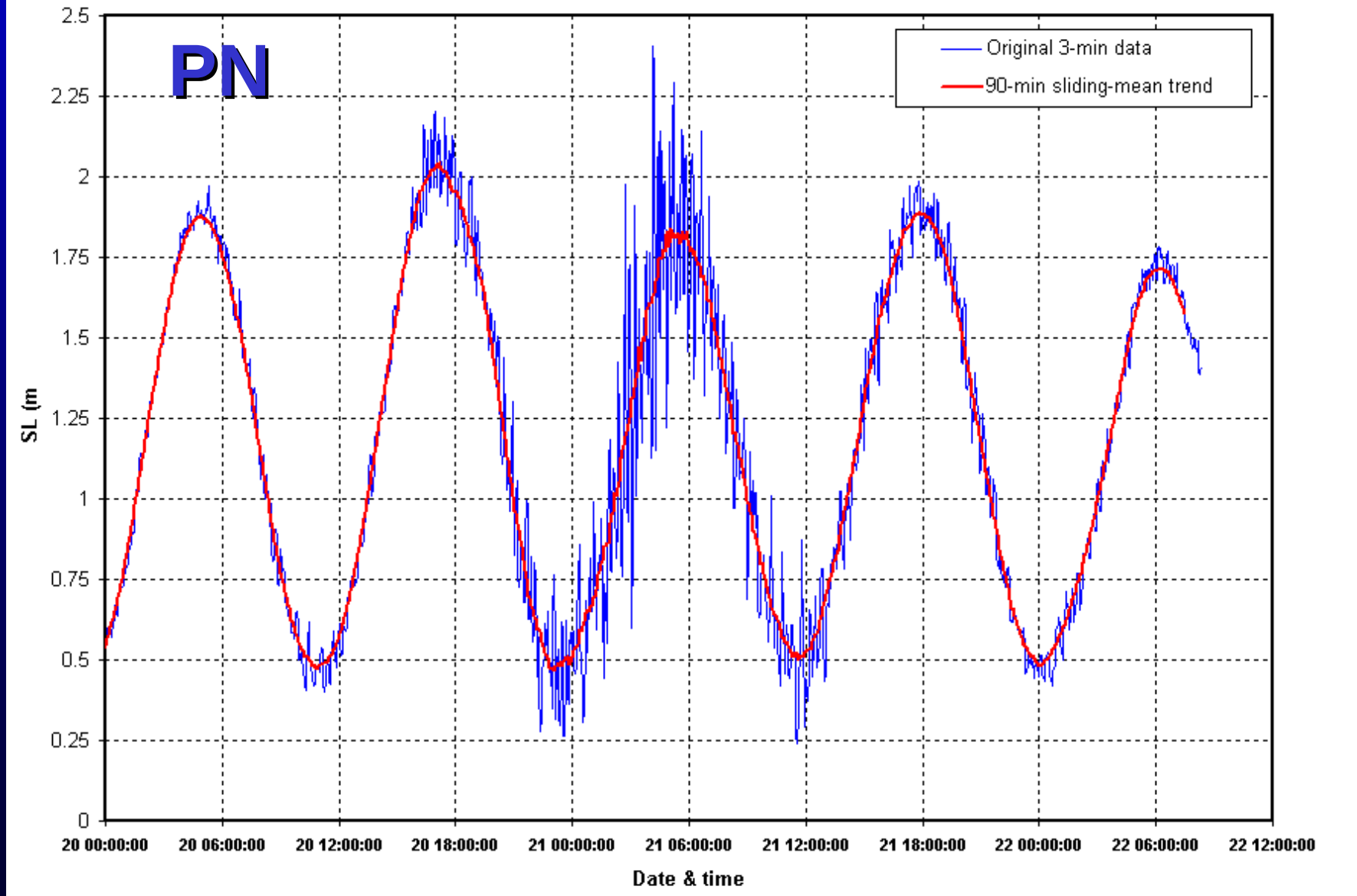
JOHANNESBURG, SOUTH AFRICA Aug 24 2008 10:53

0 comment(s) | Post your comment

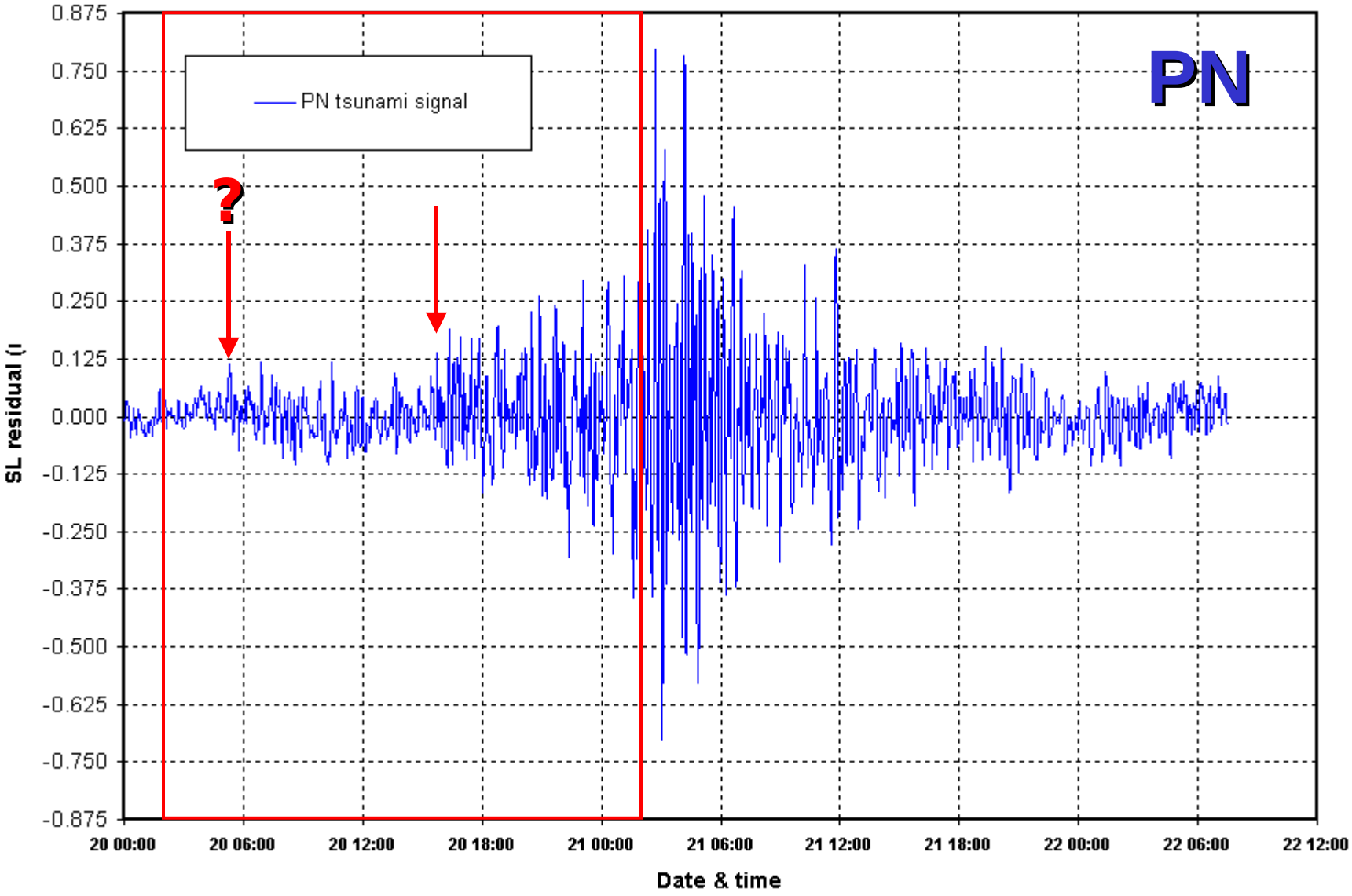
A mini-tsunami has hit the Cape West coast without prior warning, the South African Broadcasting Corporation reported on Saturday.

Weather experts said unusual tidal patterns had been reported since Thursday and there had been some damage to buildings along the St Helena Bay coastline.

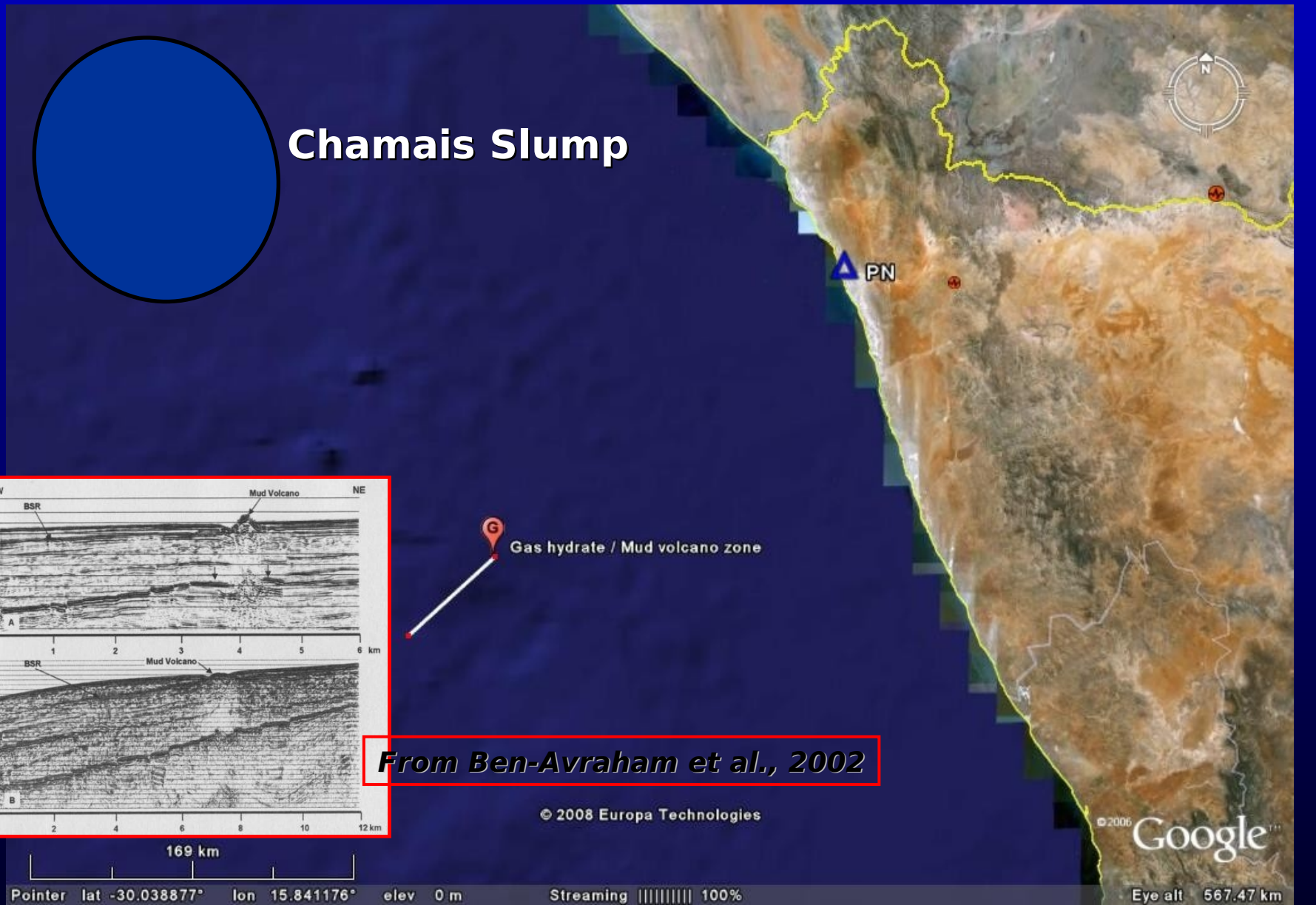
Port Nolloth tide-gauge



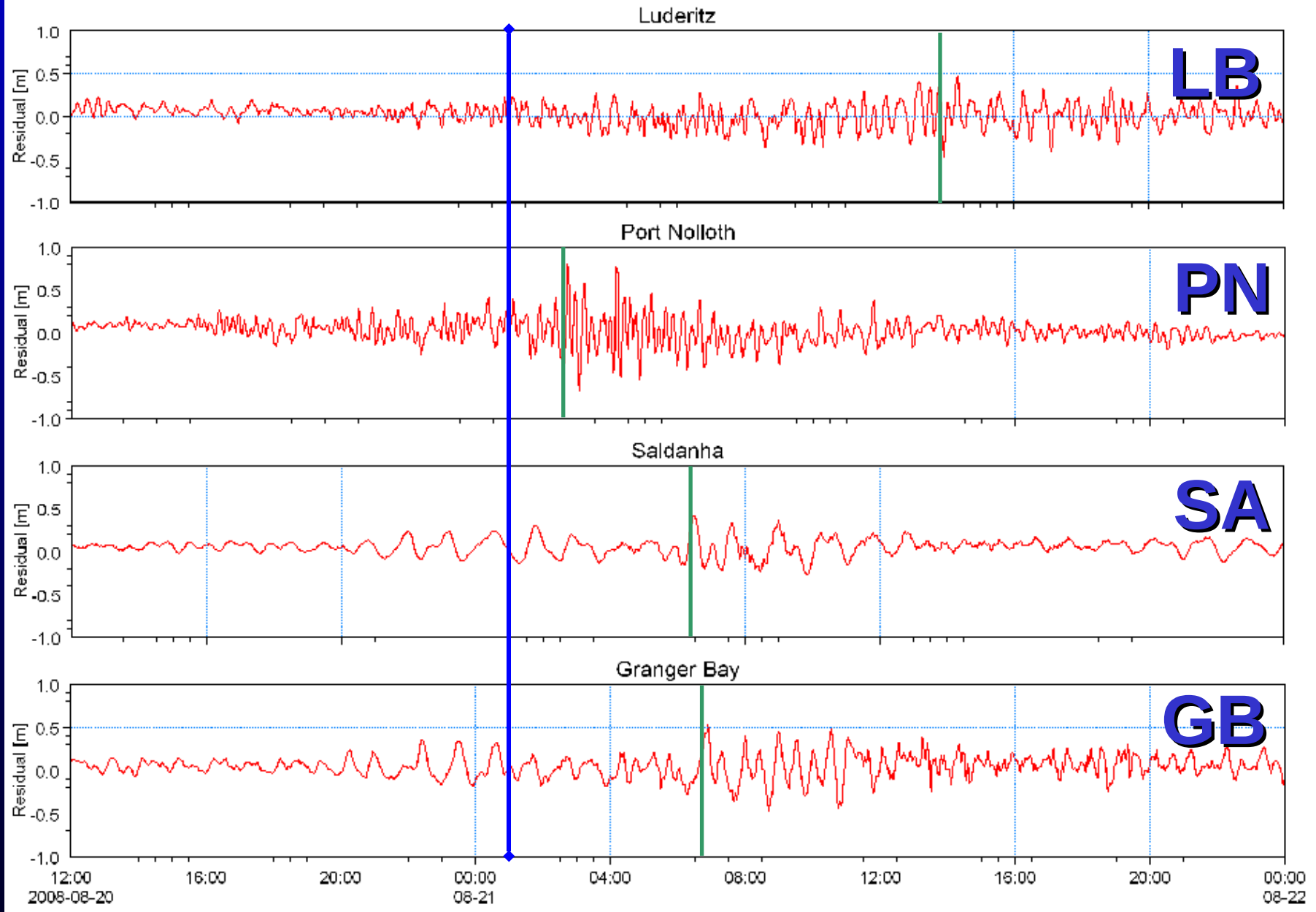
PN sea-level residual



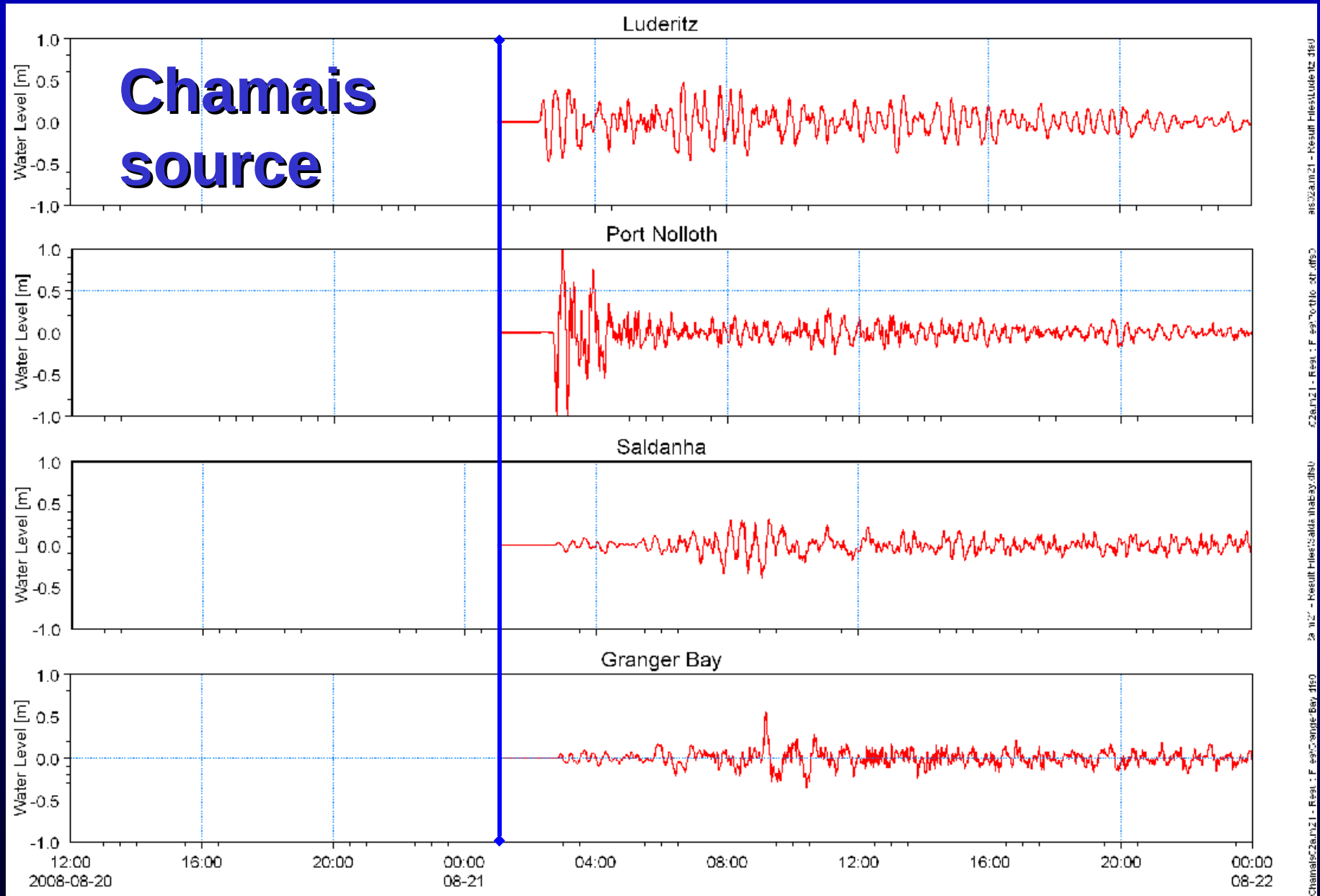
Submarine landslide sources



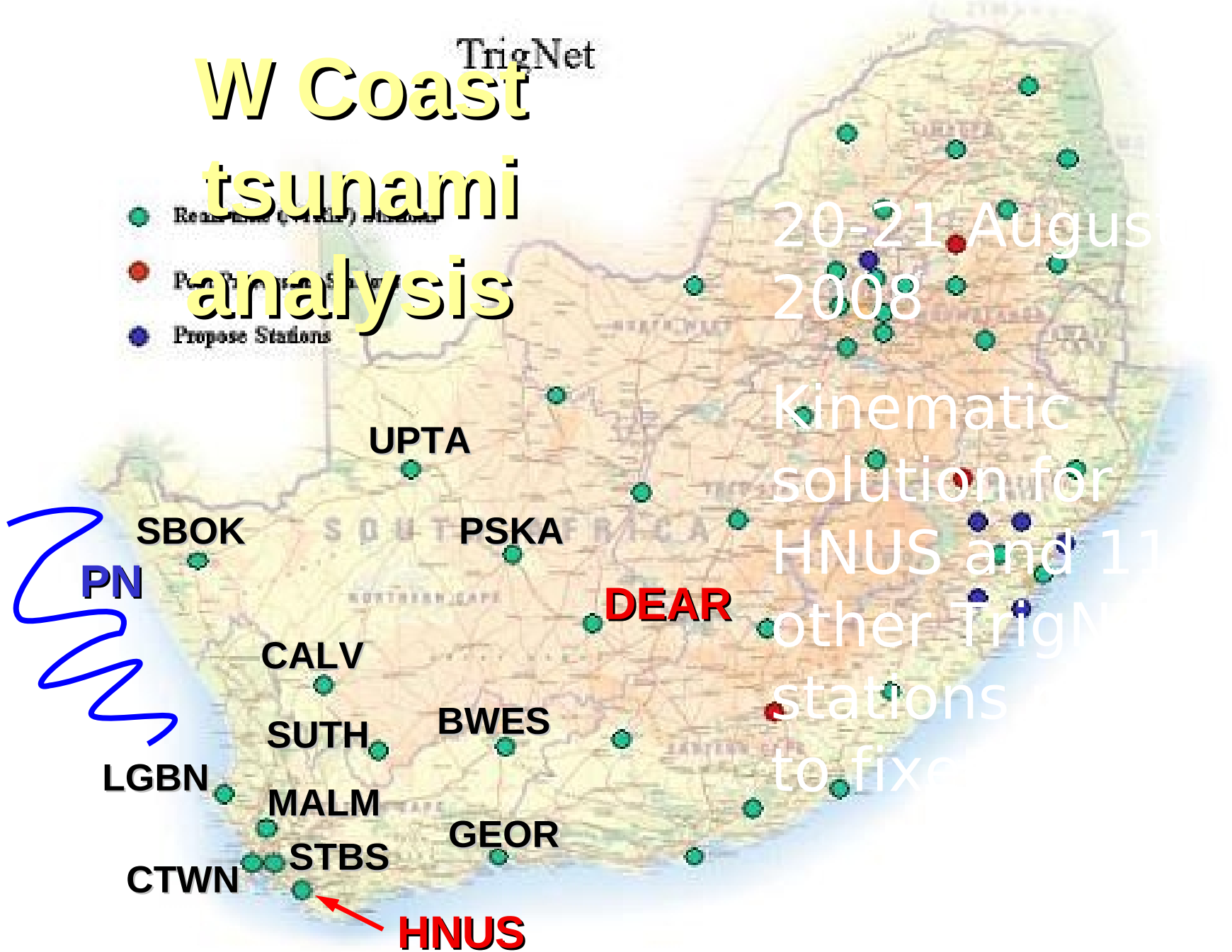
Observed sea-level residuals



Modelled sea levels



W Coast tsunami analysis



20-21 August 2008

Kinematic solution for HNUS and 11 other TrigNet stations to fixed

HNUS results