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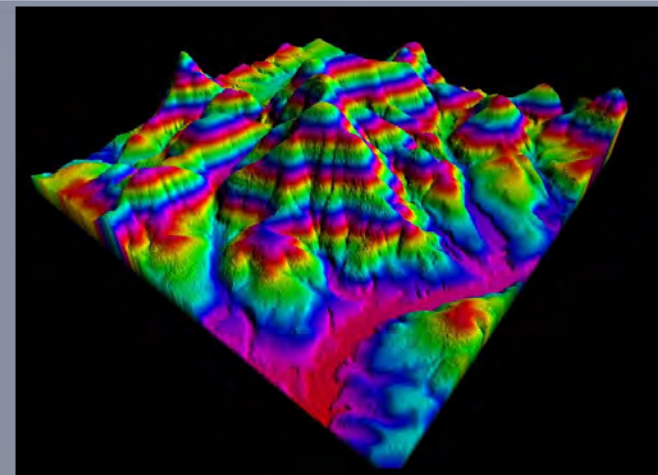
Thank you.

Introduction



Practical considerations for boundary survey work.

1) Merrett Survey – Boundary Experience
2) Field work – Considerations
3) Co-ordinate systems
4) Airborne Laser Scanning (ALS or Lidar)
5) Additional technologies – UAV (drones) and satellite imagery

<u>Introduction</u>

Peter Merrett of :-

Merrett Survey Ltd
UK based working Worldwide – 60 countries to date

Providing :- **ALL types of geomatics / topographical surveys**

Specialisations include:-

Geodetic work – including Boundaries
Airborne Laser Scanning (Lidar)
Terrestrial laser scanning (TLS / HDS)
'Standard' topographical surveys

Working as survey 'contractors' or consultants

Introduction

Merrett Survey Ltd
We have opened a subsidiary office/company in Cameroon

This is named Africa Precision SARL

Please refer www.africaprecision.com

Via this company we can provide all of the same services throughout Africa.

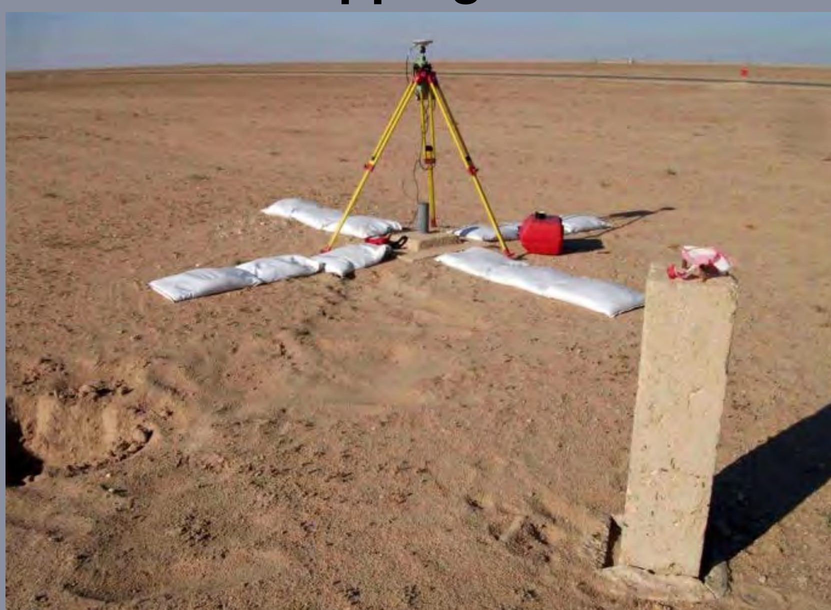
International Boundary Work

Kuwait – Kingdom of Saudi Arabia – (NZAM) – 2011 / 2012

Replacement / renewal of existing markers.

Update of co-ordinate system used to define the boundary.

New Aerial mapping.

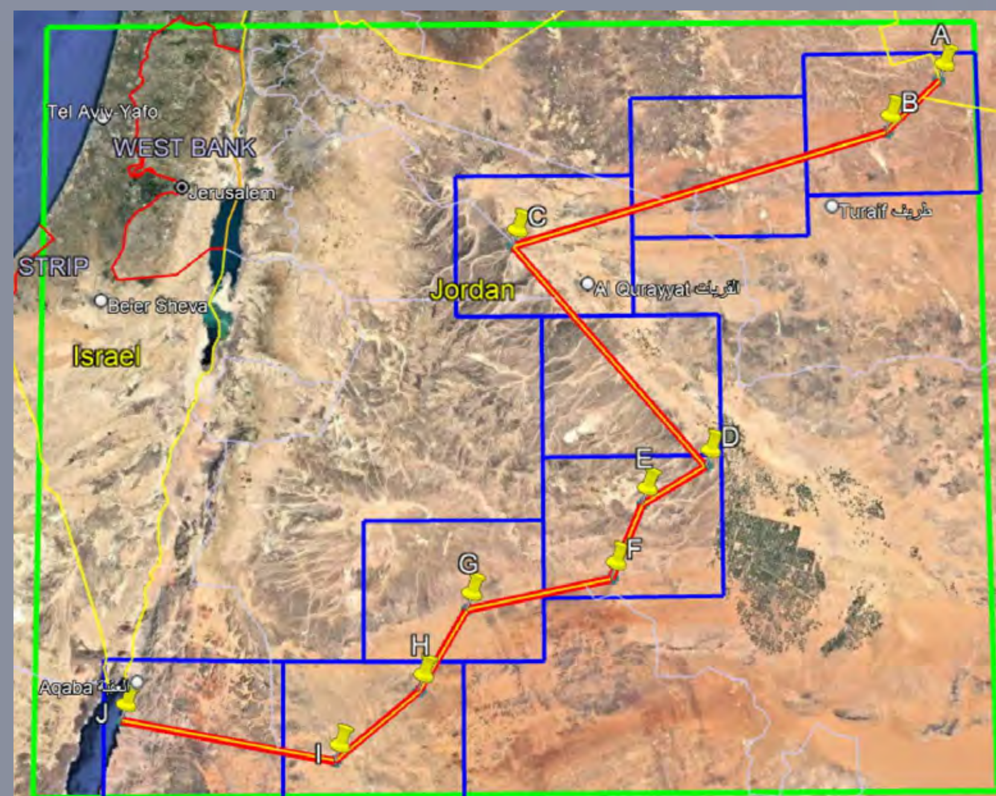


<u>International Boundary Work</u>

Jordan – Kingdom of Saudi Arabia – 2022-2023

Replacement / renewal of existing markers.
Additional markers (densification for inter-visibility).
Update of co-ordinate system used to define the boundary.

We have tendered for this work but wait to hear the results.



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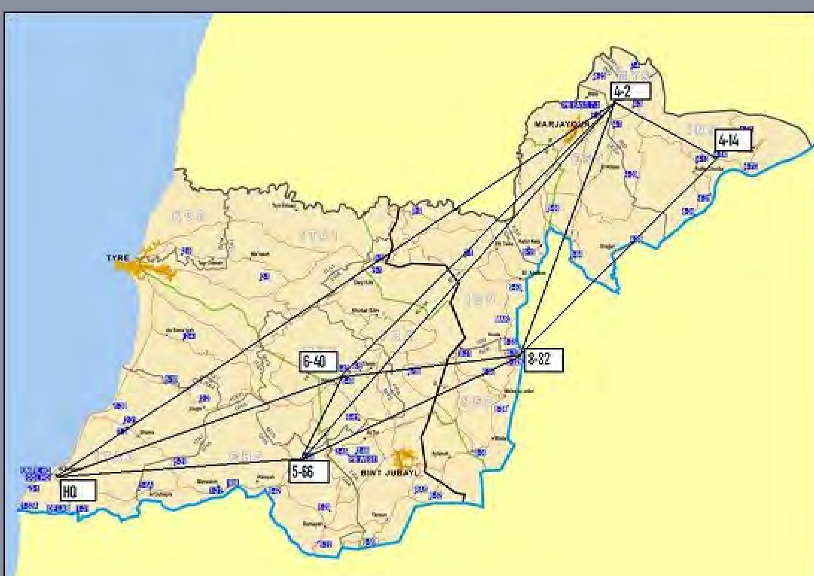
International Boundary Work

Southern Lebanon – Blue Line – 2010
(UNIFIL – United Nations Interim Force in Lebanon)

Installation of a 'real time area wide DGPS' for use by UN in recording boundary and 'incident' data.



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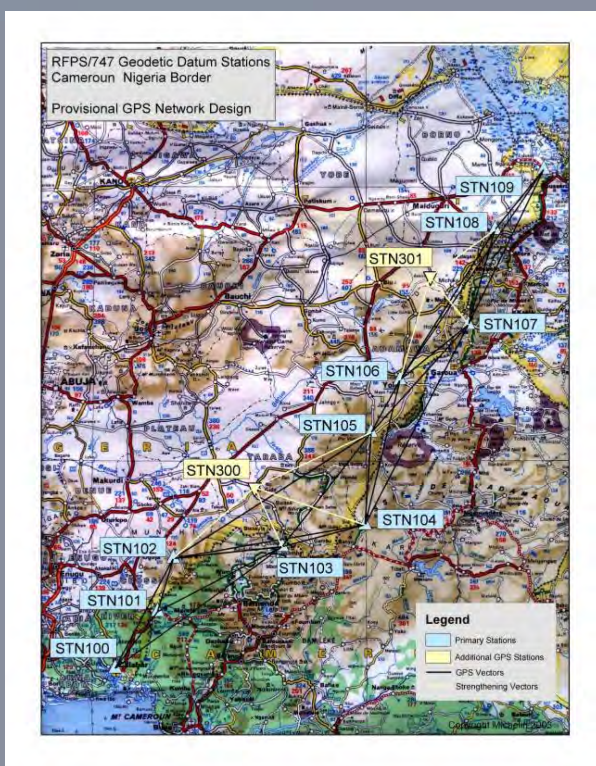
International Boundary Work

Nigeria – Cameroon (United Nations) – 2007 / 2008

Placement of geodetic control – from which the boundary has been measured.



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International Boundary Work

Kuwait – Iraq
2013 - United Nations

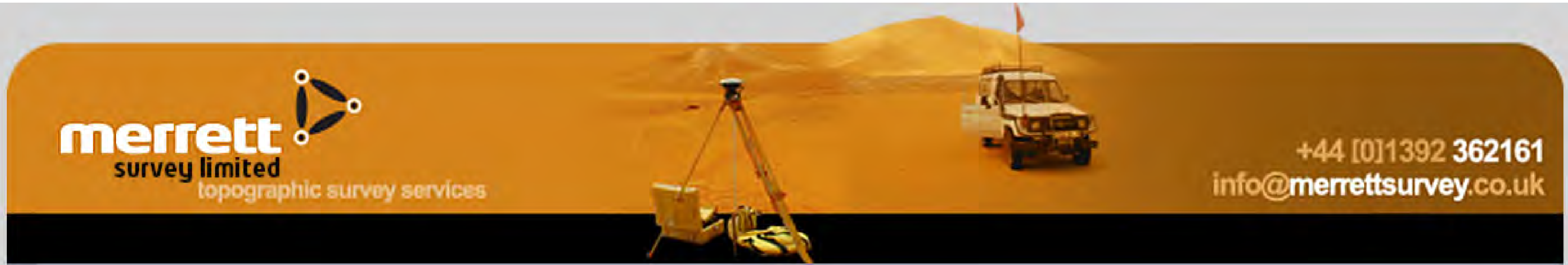
Replacement / renewal of existing markers

Malawi – Mozambique
2013
European Union (GIZ) funded

Determination of the watershed in order to define the boundary

Ethiopia – Eritrea
2004 – United Nations

Note that Merrett Survey were awarded the placement survey and geodetic survey of the new pillars by the UN. But hostilities broke out again and the work did not proceed.



<u>Field work – Practical considerations</u>

This presentation assumes that the work to 'define' the boundary has been completed. The factors below will be illustrated using real life projects.

<u>Planning</u>

Reconnaissance – saves a lot of time later on (can use the information gathered during any previous field visits)

Planning – travel times – local resources (construction materials)

Logistics – how many people / vehicles / accommodation / food

Political issues and sensitivities – involve the local population
Access
Security / Safety (UXO etc)

Budget

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Field work – Practical considerations

Choice of co-ordinate system

How to set the markers in the right place.
Survey methodology – need to include proof of accuracy.
Independent verification / quality control.

Monumentation

Do you need physical pillars ?

Type of monument. Do you need Witness marks / Pointer pillars ?

Choosing the location of monuments
(Turning points plus intermediates ? Spacing ? Intervisible ?)

Forest – Rivers – where to put the point?
GPS won’t work well in the forest.

Field work – Practical considerations

Applying these considerations to real life projects, we will look at International boundary projects for:-

Saudi - Kuwait

Lebanon

Nigeria – Cameroon

Field work – Practical considerations

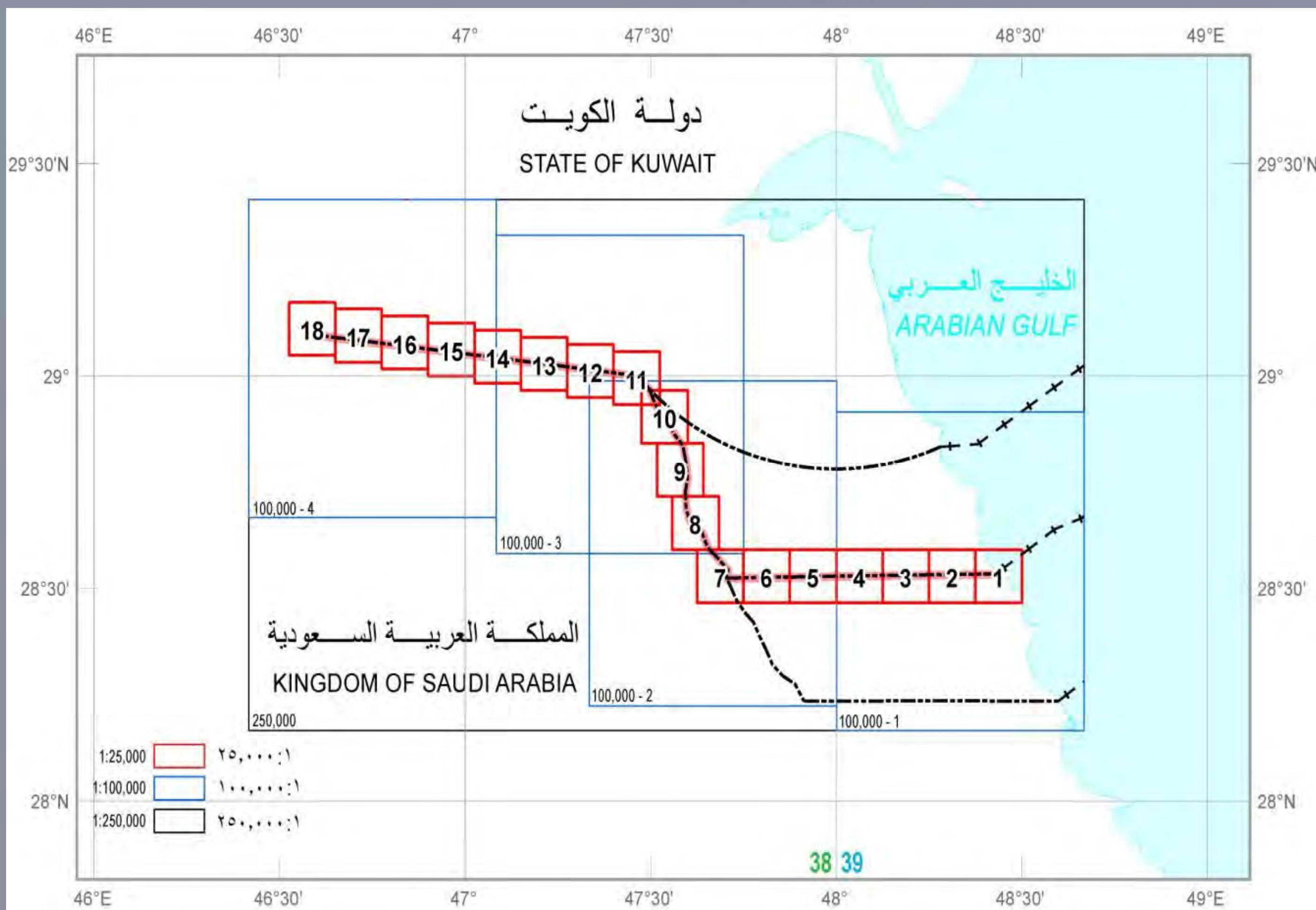
Saudi – Kuwait

Respective Governments issued an RFP for the work to include:-
Surveying the existing ‘deteriorated’ pillars.
Create control to enable replacement in same place.
Survey the ‘as-built’ location of the new pillars to high accuracy.
New aerial mapping (photogrammetry) of the border area.

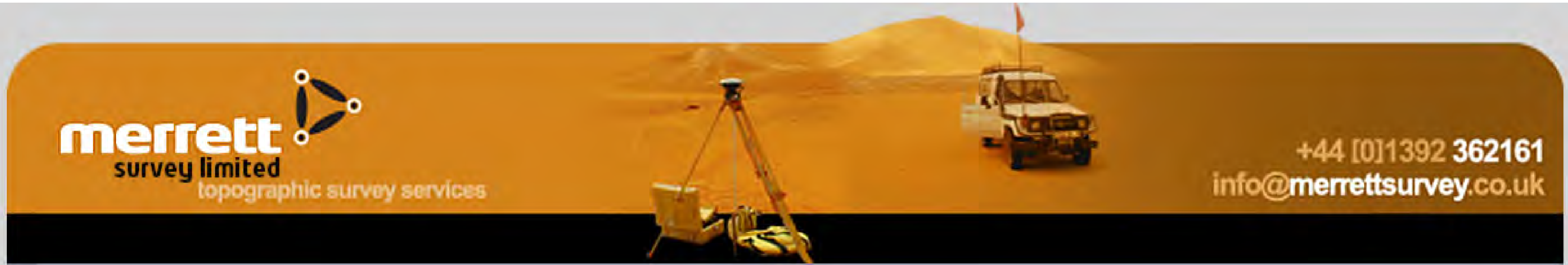
Logistic – specific problems

New co-ordinate system – tied in to control networks in both countries
Needed a camp
Needed to cross the border daily
Two points built in the sea
UXO – cleared in previous years

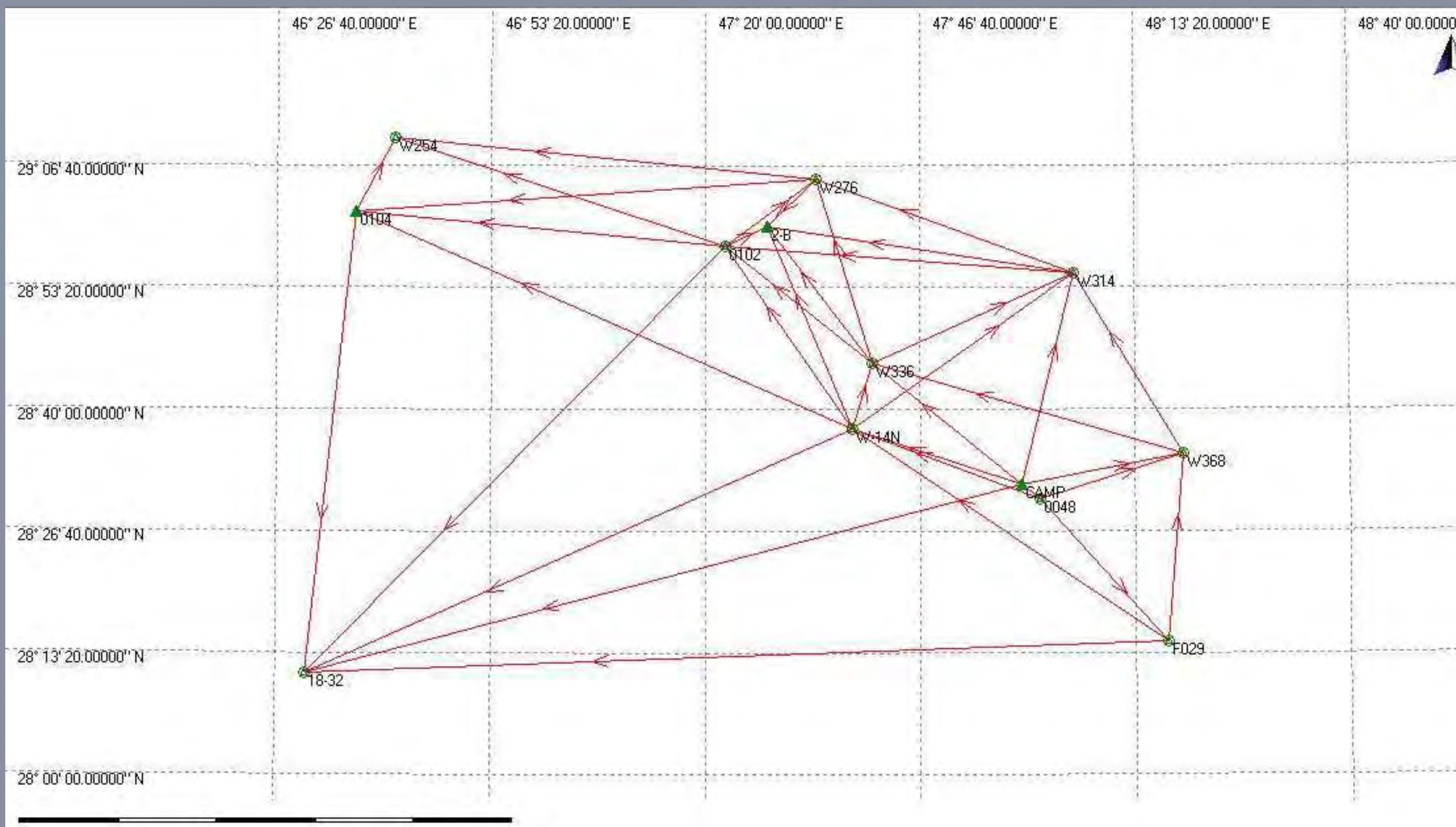
Saudi – Kuwait



Boundaries and layout of new aerial mapping



Saudi – Kuwait



Primary control network – includes 10 existing control stations, 5 in each country. Surveyed using dual frequency GPS in closed loops, with repeated vectors (redundancy) to ensure proof of accuracy.

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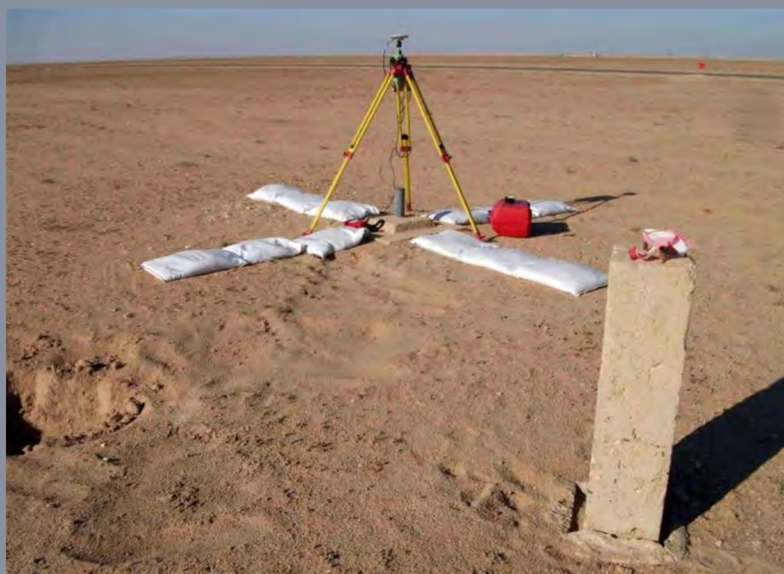
Saudi – Kuwait



Existing pillar occupied with GPS and pre-marked for aerial mapping

Temporary camp was established close to the border

13 GPS units were used. Calibration of all equipment is important.

Reference marks built around existing pillars, and they are surveyed using conventional survey methods.

Old marker removed. **New pillars are ‘surveyed into’ same location.**

Saudi – Kuwait – Pillar design

Two different types specified for the different boundary 'types'

91 no. Type 1 markers along the Boundary

56 no. Type 2 for the Northern and Southern Lines of the Partition Zone

Type 2 – 'as built' survey by GPS

Type 1 installed

Saudi – Kuwait

Top of pillar – threaded bolt enables 'forced centering' of survey instrument.

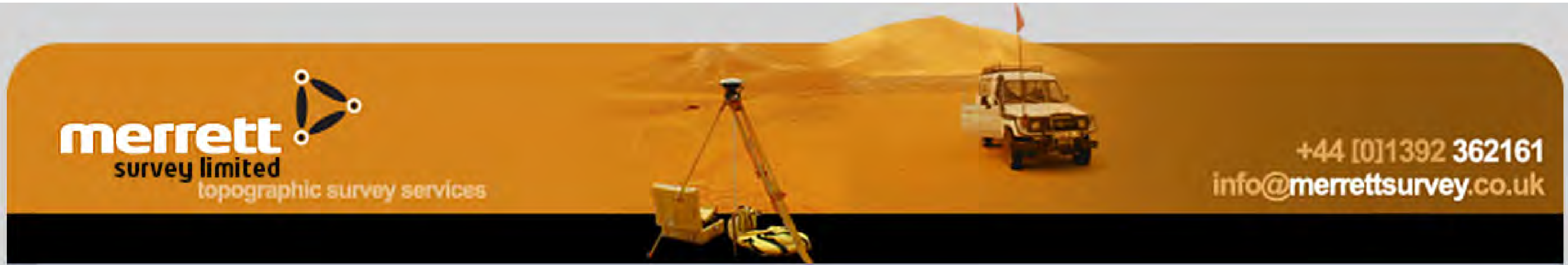
Delivery of Type 1

Type 1 markers – drilled and 'pinned' with stainless steel pipes

Saudi – Kuwait – Coastal points

Original coastal pillar (in tidal zone)

Replacement ‘pillar’



<u>Field work – Practical considerations</u>

Applying these considerations to real life projects:-

<u>Lebanon</u>

Purpose – To provide UNIFIL with a high accuracy method of confirming measurements made by Lebanese and Israeli surveyors along the 'Blue Line'.

Method – UNIFIL issued a competitive tender for installation of a local real time DGPS and CORS survey system. Plus new survey control points, within UNIFIL camps. Plus training of staff.
(CORS = Continuous Operating Reference System)

Co-ordinate system used – ITRF2005 (Epoch 2010.7712)

Lebanon

Reconnaissance visit was made to decide on location of new base stations.

Then construction / infrastructure placed (power supply and computer network connections built by UNIFIL).

Then we returned to install GPS equipment / software. Surveyed new stations for future expansion, and movement of the equipment.

Tied to IGS stations to confirm ITRF co-ordinates.

All stations surveyed and adjusted in closed loops.

Training given.

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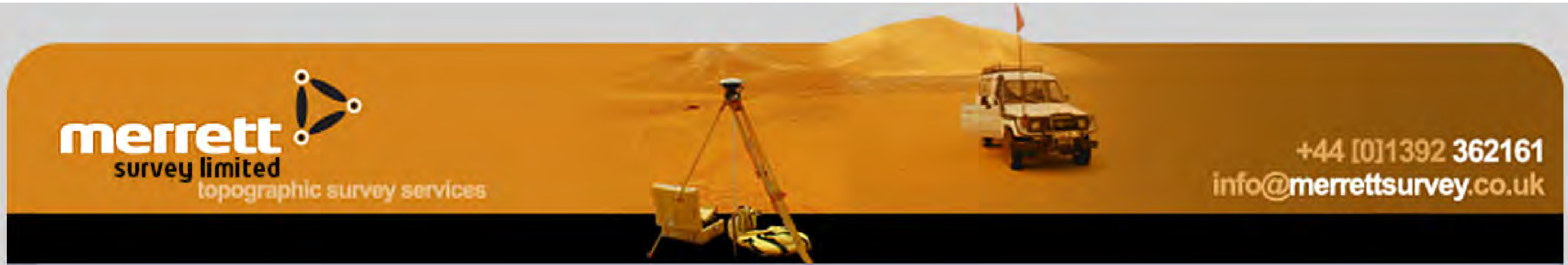
Lebanon

Data gathered at the co-ordinated CORS points was processed via computer network and RTK corrections broadcast to a 'rover' GPS unit.
20 km ranges from base stations shown below.



Nigeria – Cameroon

1800 km to be demarcated after International Court of Justice ruling.
UN (on behalf of CNMC) issued an RFP for the control network.
(CNMC = Cameroon Nigeria Mixed Commission)

Phase 1 - Merrett Surveys – Built the Geodetic control stations.
10 no. Primary (5 in each country) with 4 reference marks.
30 no. Secondary (15 in each country) with 2 reference marks.
Phase 2 – Merrett Surveys tied to IGS for ITRF co-ords.
Observed and adjusted the network.

Training of counterpart staff from both countries also provided before and during the field work. Four GPS units handed over on completion.

CNMC agreed border locations during field visit and were recorded by the UN surveyors using 1m accuracy DGPS.

UNOPS managed local contractors to set-out the new pillar locations and build the boundary pillars.

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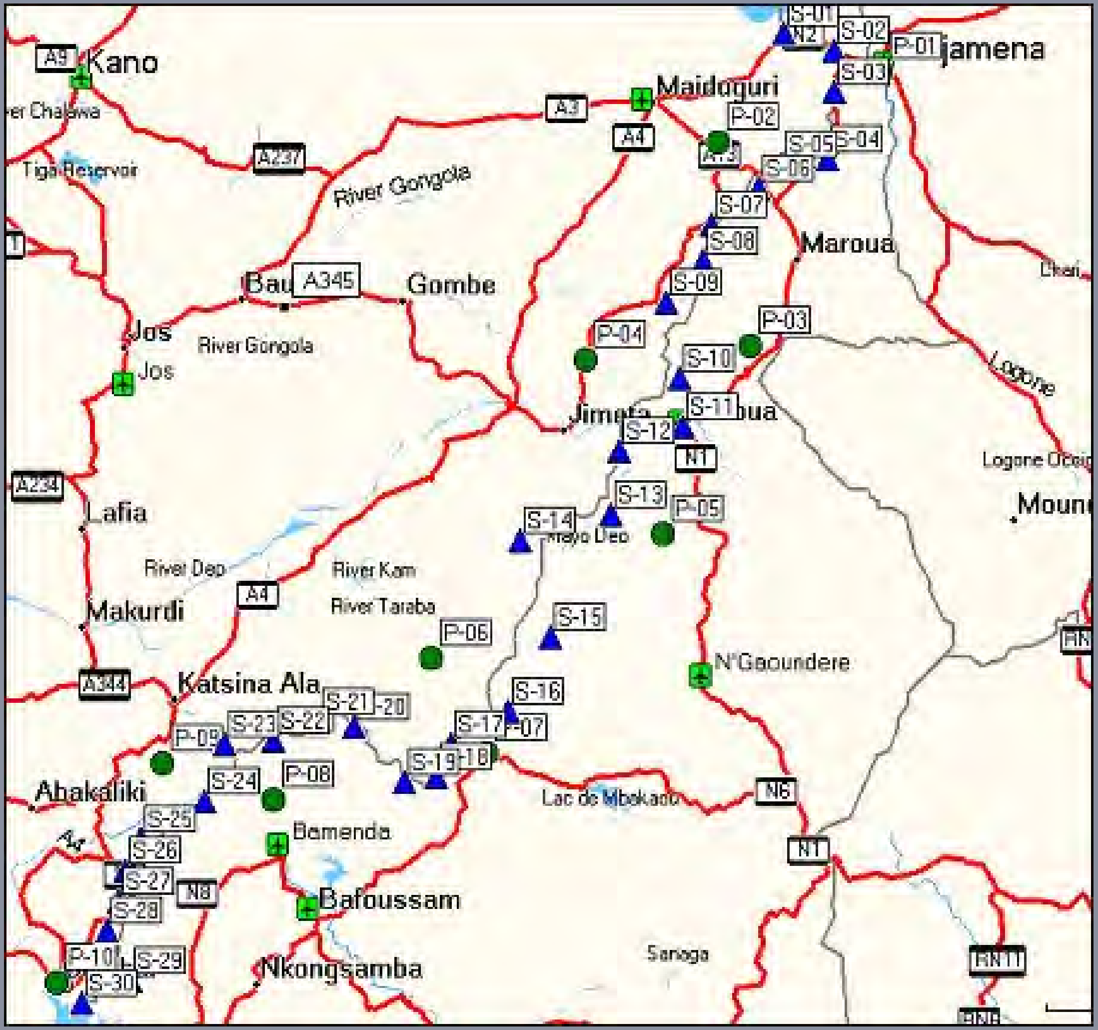
Nigeria – Cameroon

Layout of control stations close to but not ‘on’ the Boundary.



Nigeria – Cameroon

Logistics / planning / methods

Terrain included: desert, mountains, forest

CNMC had already travelled the border and were very helpful in pre-planning realistic routes and locations with accommodation.

Phase 1 work - We had 1 team in Nigeria, 1 team in Cameroon. Those teams split in two. One scouting ahead and agreeing the locations, plus researching building materials. Then construction team followed up.

Phase 2 work – 4 GPS teams all observing simultaneously, then 2 move so as to create ‘braced quadrilateral network’. 12 no. GPS units, and observing the reference marks at same time.

Note – the location of the stations often a compromise between politics and best survey practice. Each border ‘District’ wanted a station in their territory.

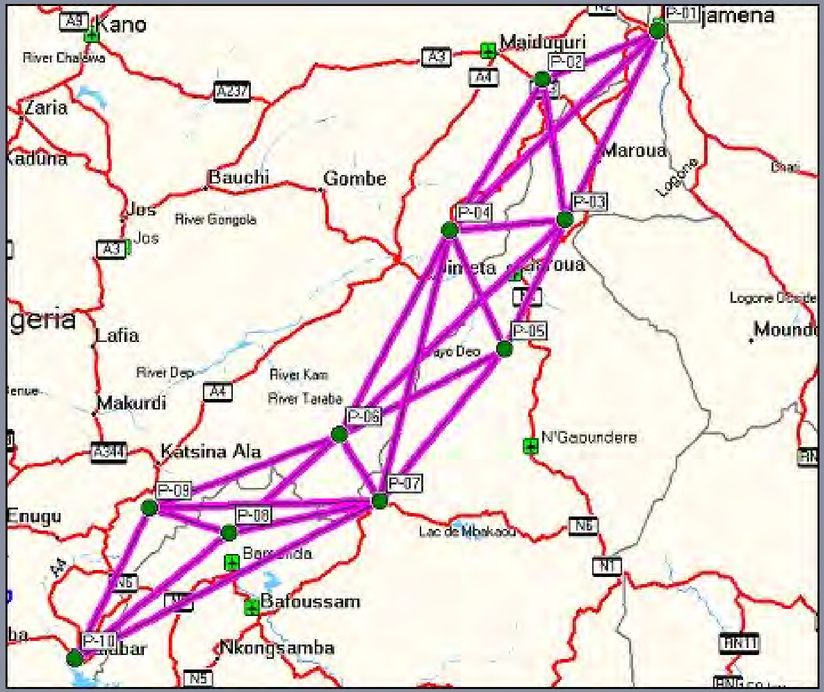
<u>Nigeria – Cameroon</u>

Complex design of station was revised to a 1 buried metre cube of concrete. Built in-site (not pre-cast). Reference pin ‘buried’ beneath that. Brass plaque at centre.

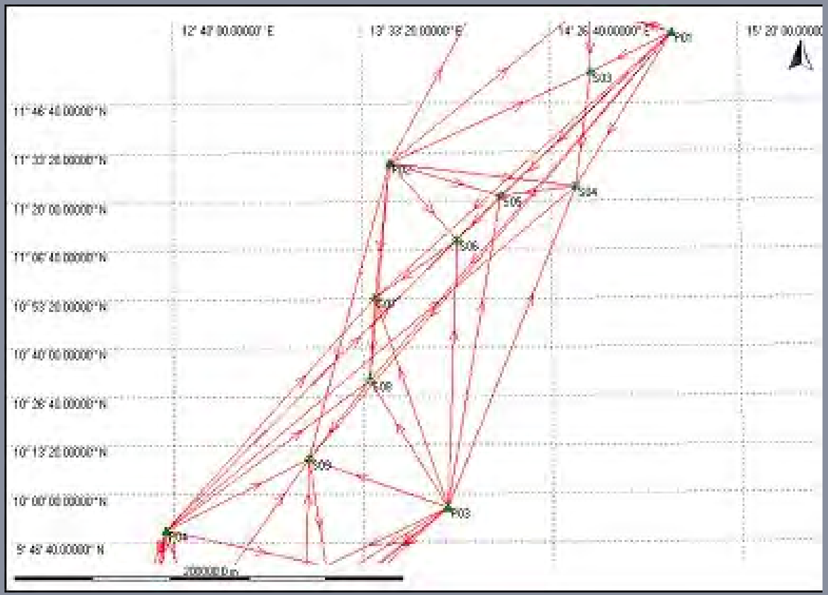
Nigeria – Cameroon

GPS observations

Primary network



Segment of Secondary network



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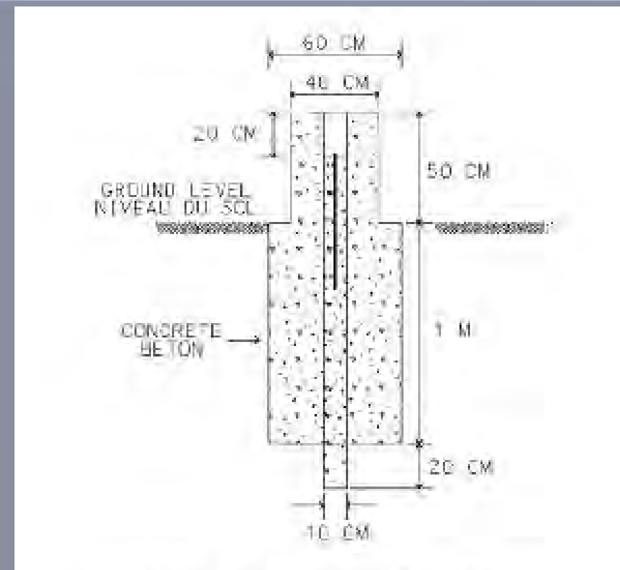
<u>Nigeria – Cameroon</u>
Boundary pillars – Supervised by UNOPS (Merretts not involved)



Intermediate Point Boundary Pillar

Construction by local contractors

NOTE – Demarkation not yet completed.

Inspection of the inaugural pillar

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GPS (GNSS) – exploding some myths

GPS = US military system. GNSS is the correct term now (Global Navigation Survey Systems) includes Glonass (Russian), Galileo (European), Compass (Chinese).

Navigation accuracy – was 100m, but is now 3m to 10m.
Differential GPS is a must for higher accuracies. This reduces the errors.

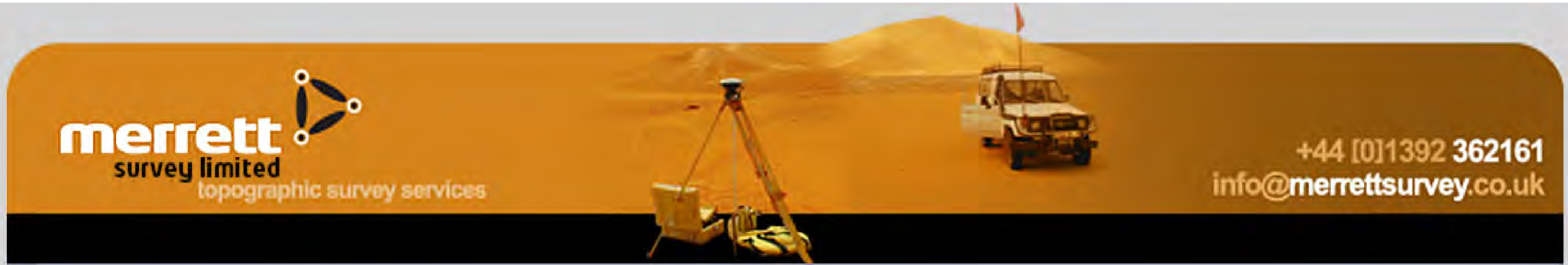
1m (or ‘sub-m’) accurate DGPS (eg Omnistar) – read the small print. Only that accurate 68.3% of the time.

Geodetic accuracy – need dual frequency ‘high end’ equipment.

Relative and Absolute accuracy – important differences.

Does the co-ordinate I get come from the satellites ?
For navigation accuracy – yes. For high accuracy work – no. You need to measure from a known point.

GNSS processing is an exercise in statistics. The more data you collect, the more ‘likely’ you have the right answer. This means long observation times.



Co-ordinate Systems (Geodetic datums)

As measurement methods improve, we get more and more accurate geodetic systems from which to make maps and to measure our location. What are the consequences of changing and updating datums ?

Example

NAD27 (North American Datum 1927) – Clarke 1866 ellipsoid
Geodetic centre at Meades Ranch, Kansas (centre of USA)

Then updated to

NAD83 (North American Datum 1983) – Uses WGS84

Consequence – Lat / Long in old system is 100m different to new system in Gulf of Mexico. New oil rigs placed in wrong locations, pipelines on sea bed fractured by anchors etc.

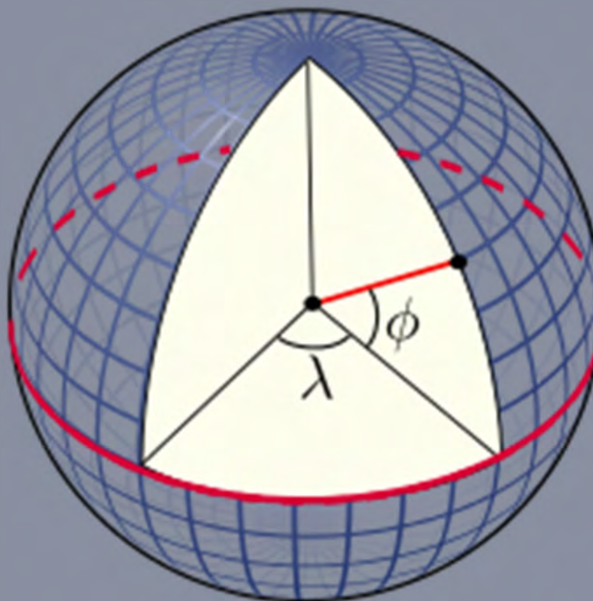
Co-ordinate Systems (Geodetic datums)

Some questions we can look at:-

- **In what 'system' (or systems) has the boundary been defined ? (Historical documentation and records).**
- **We need to consider these to get the boundary in the right place.**
- **Two or more countries may have different (historic) datums and map projections. Do you create a new datum ?**
- **Why use the latest datum ? Chance to modernise.**
- **Enables the boundary to be re-established if all the markers are destroyed.**
- **What is a Geodetic Datum ? A reminder.**

Co-ordinate Systems (Geodetic datums)

What is a Geodetic Datum ?



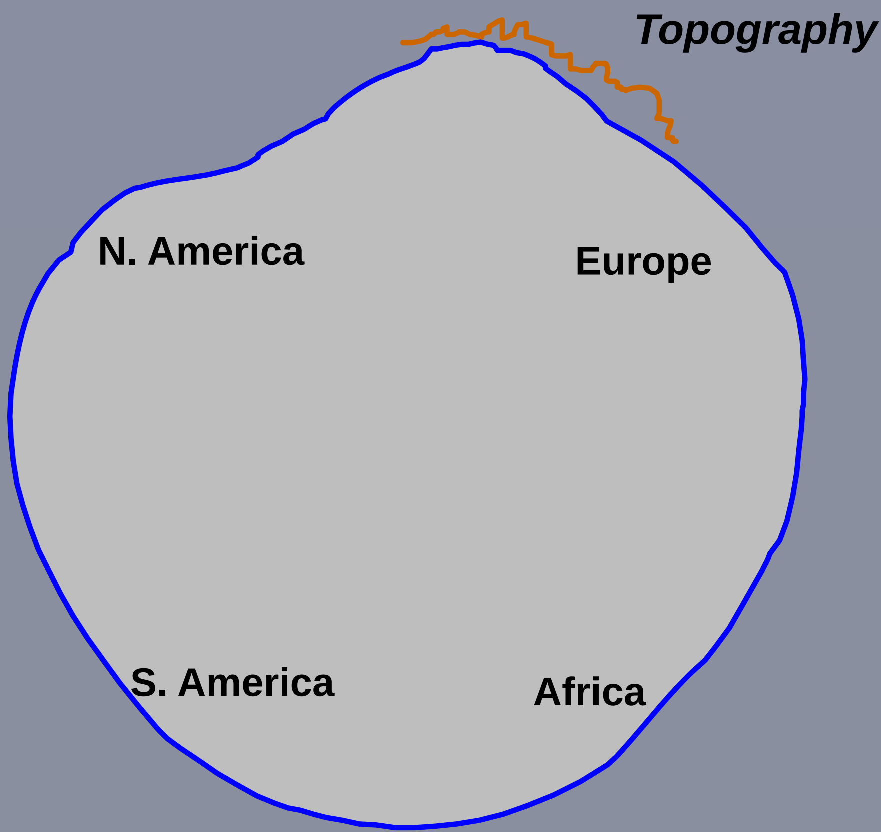
A reference frame – from which measurements are made.

An ellipsoid in a defined location.

A mathematical representation of the shape of the Earth.

Co-ordinate Systems (Geodetic datums)

The Earth is not a perfect mathematical shape



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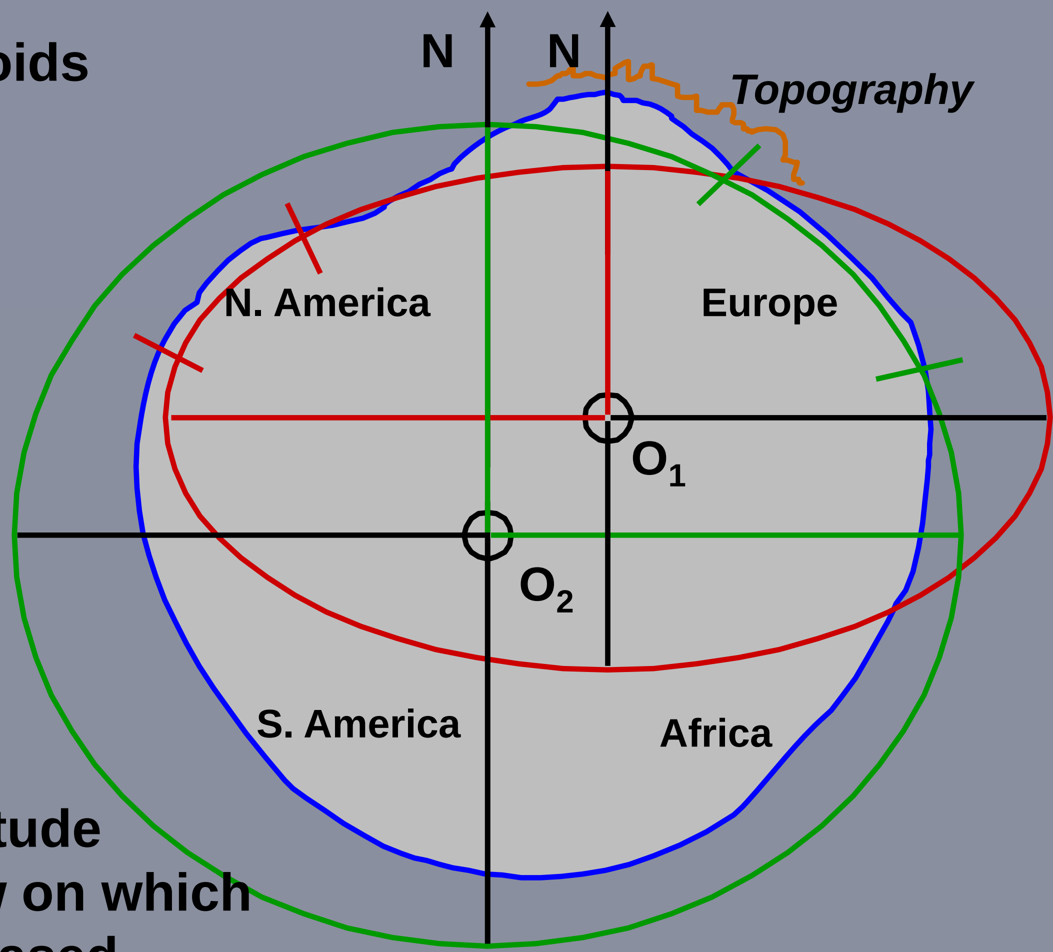
Co-ordinate Systems (Geodetic datums)

There are many ellipsoids
to choose from.



Remember

To define a point
by Latitude and Longitude
you also need to know on which
Geodetic Datum it is based.

Co-ordinate Systems (Geodetic datums)

WGS84

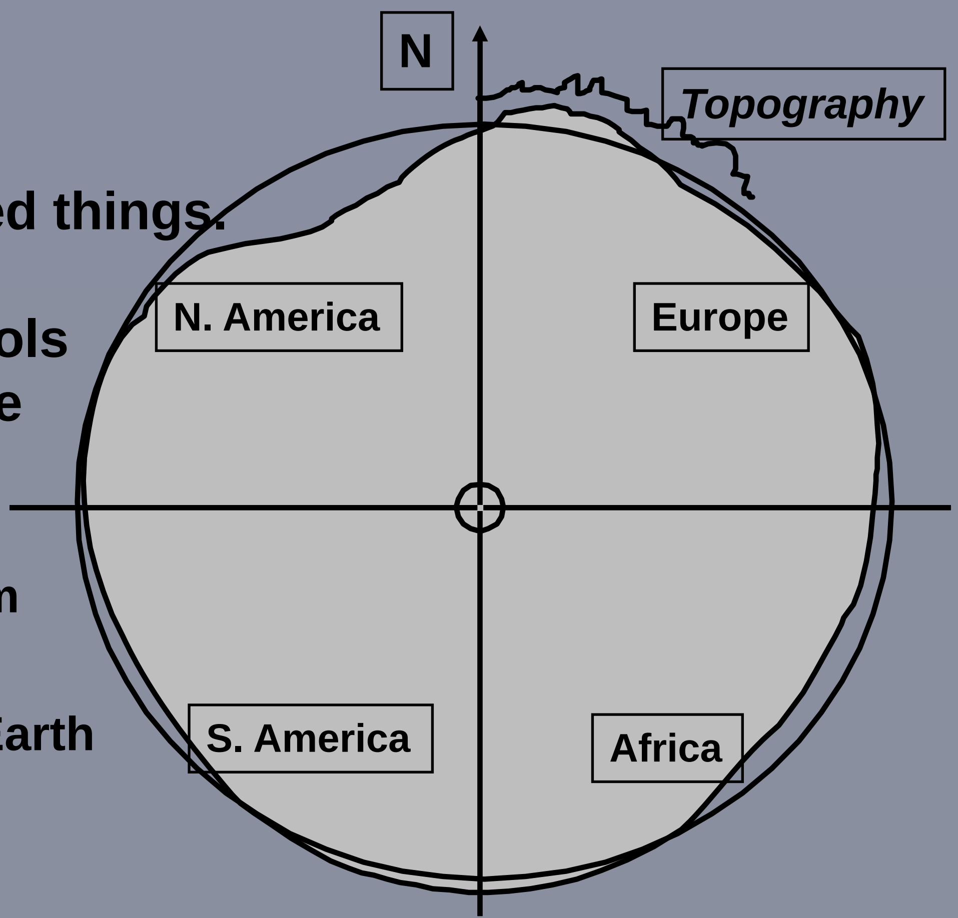
GPS (GNSS) has changed things.

We have had the best tools yet to measure the shape of the Earth.

The World Geodetic System

- **WGS 1984 uses**

a best mean fit to the Earth



Co-ordinate Systems (Geodetic datums)

Plate tectonics

Because the Earth's surface is constantly moving, you now need to record your surveyed points stating:-

Where is the point on the Earth's surface (eg Lat /Long and height above the ellipsoid surface).

Which reference frame (geodetic datum) you measure from.

And when it was at that location (stating its Epoch).

eg Our co-ordinated points on the Saudi-Kuwait border are stated as:

ITRF2008 epoch 2011.0425

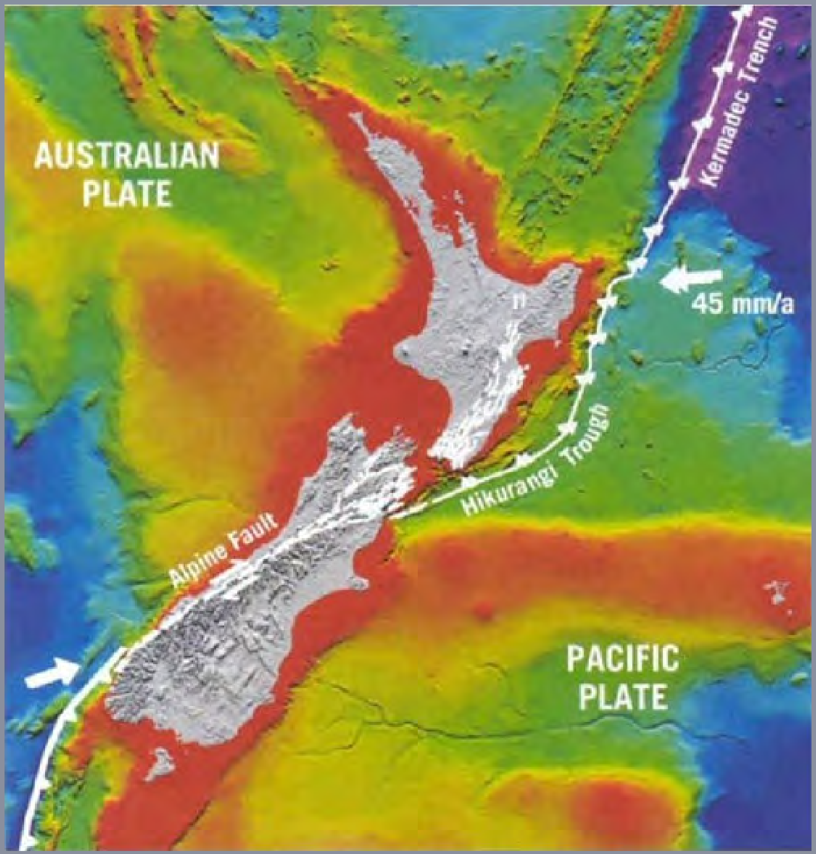
This is 4.25% of the year 2011 = Midday 15th January 2011

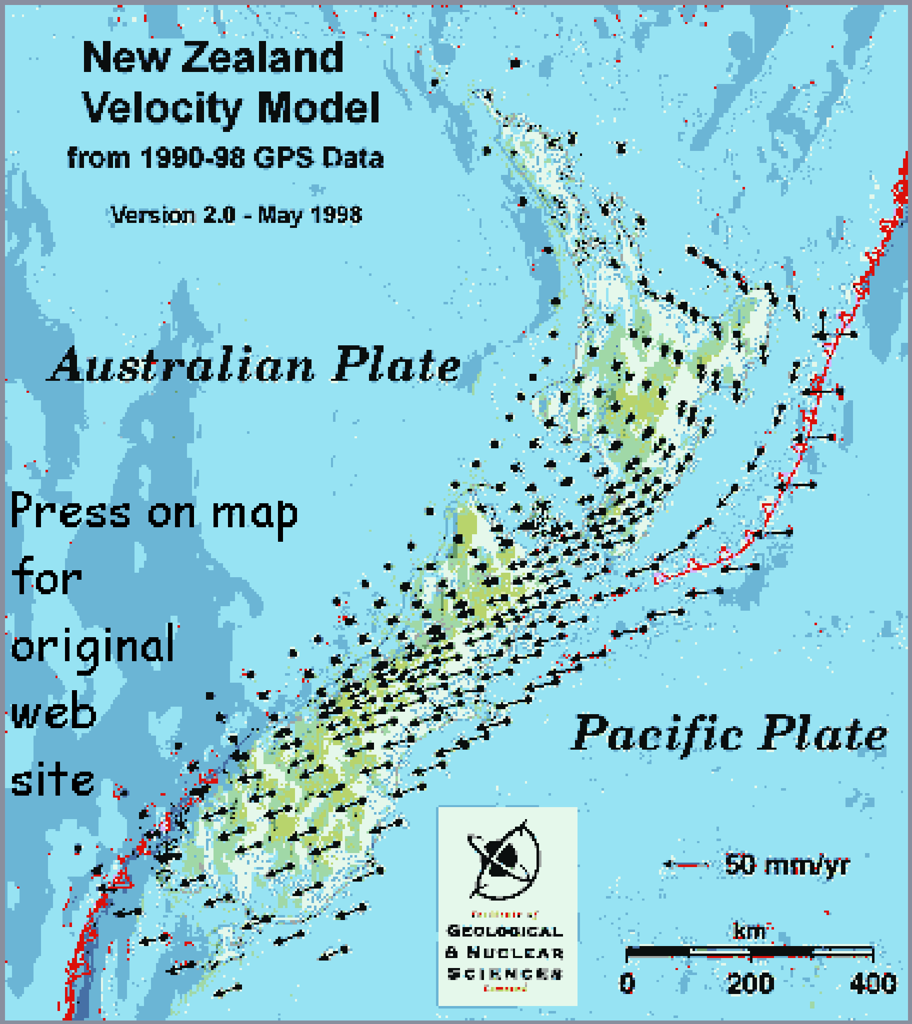
Co-ordinate Systems (Geodetic datums)

Plate tectonics
The Earth's surface is constantly on the move

Co-ordinate Systems (Geodetic datums)

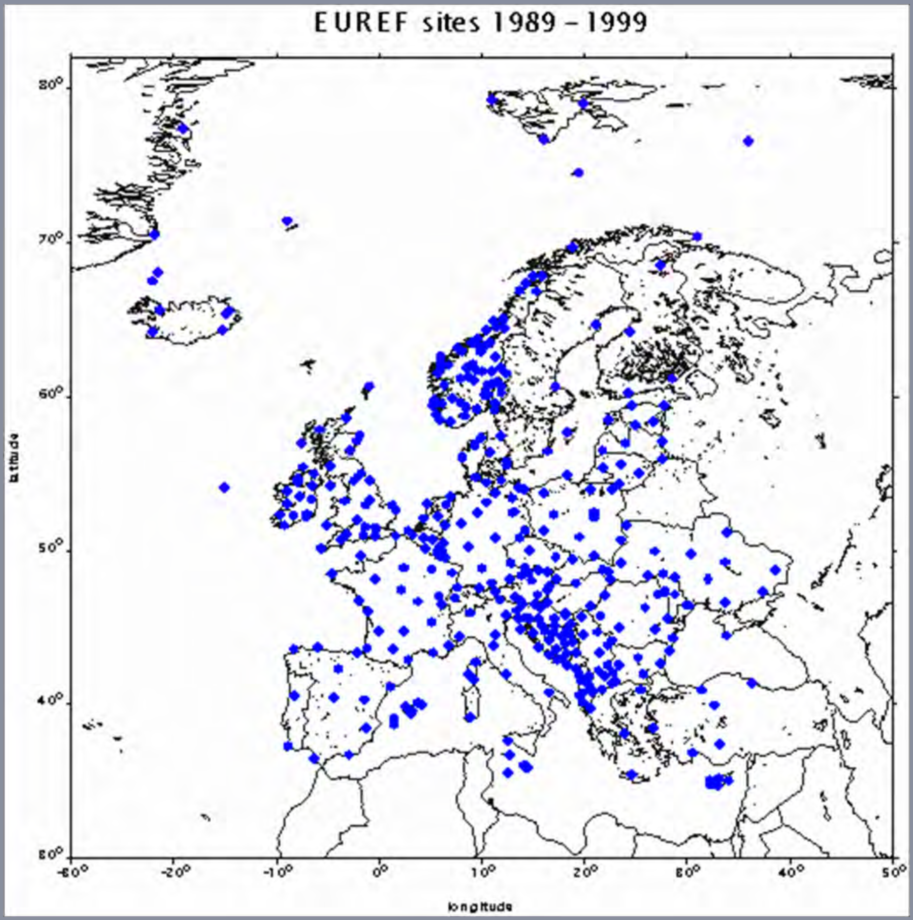
New Zealand is moving rapidly





Co-ordinate Systems (Geodetic datums)

ETRF – An example of how to get around the problems of movement.



European countries decided to connect their National control and assign their ITRF location as of 1989.

And then to 'pretend' they are not moving.

Creating the European Terrestrial Reference Frame

ETRF89 – and another geodetic 'system' is born.

Co-ordinate Systems (Geodetic datums)

WGS84 itself – has evolved through

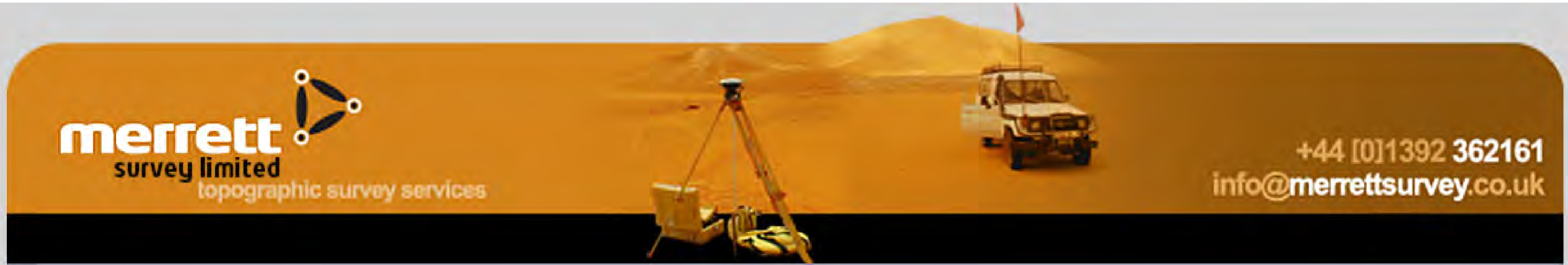
WGS72
WGS70
WGS60

Should we use WGS84 or ITRF ?

WGS84 – established by US military for ‘navigation’

ITRF – established by civilian scientific community for higher accuracy work.

Now the regular iterations of both ‘systems’ have brought them within centimetres of each other.



<u>Co-ordinate Systems (Geodetic datums)</u>

Where does ITRF come from ?

IERS = International Earth Rotation Service
Measures and updates ITRF

IGS = International GNSS Service
Co-ordinates a network of permanently monitoring GPS stations around the World – giving access to ITRF co-ordinates.
Computes station co-ordinates and velocities.

IAG = International Association of Geodesy
Promotes research and co-operation in geodesy.

Principles of Airborne Laserscanning

GPS measures the aircraft's trajectory.

Laser measures distance to ground 50,000 to 300,000 times per second.

IMU records Roll, Pitch and Yaw.

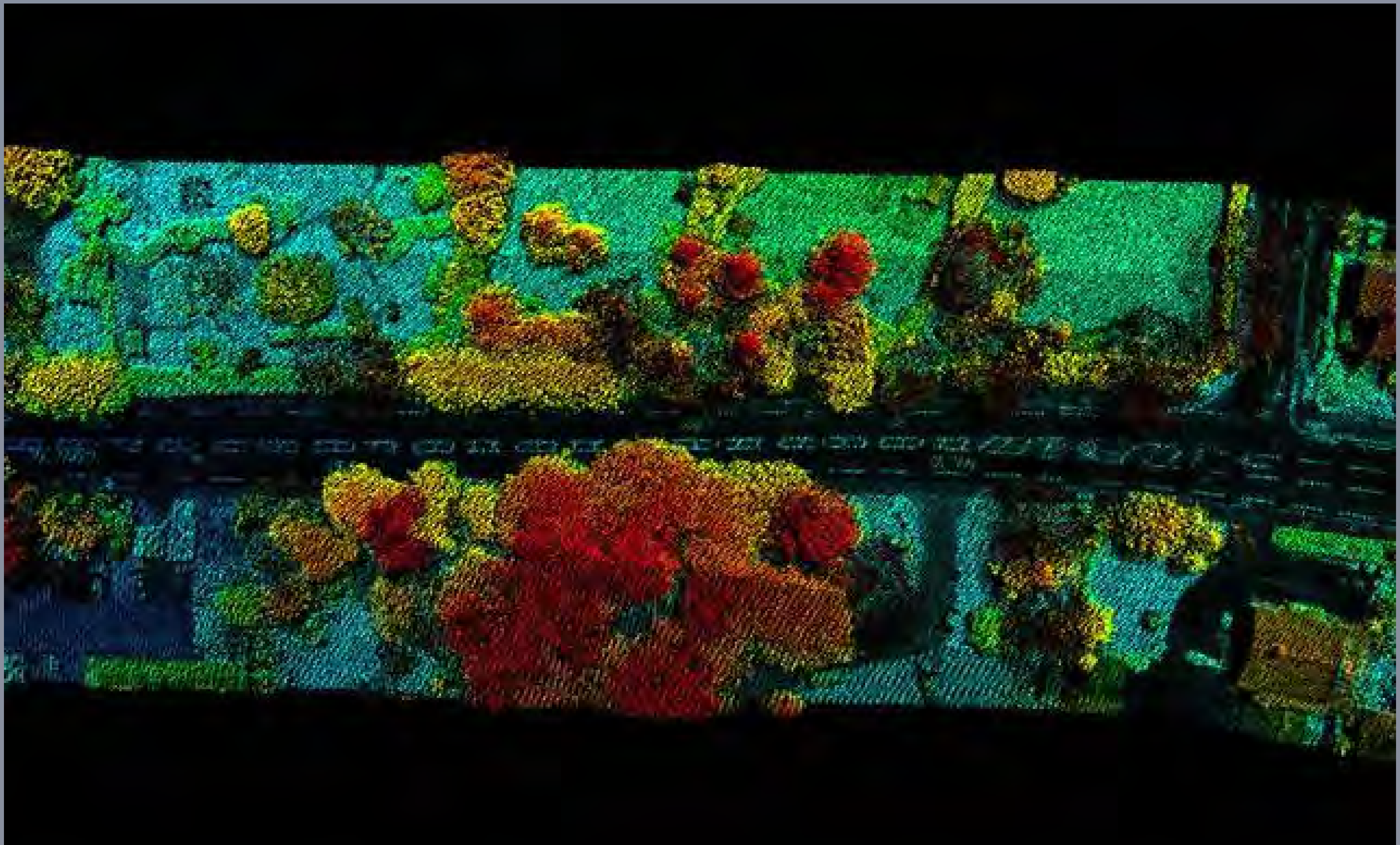
Thus Lidar 'maps' the ground shape very rapidly.

Accuracies in the order of +/- 15 cm usually quoted
Now can often be 10cm or better.

Fixed wing aircraft used to map wide areas

Helicopter mounted laser used to map ‘corridors’ – such as pipelines, railways, roads.

Data from helicopter mounted laser scanner (16 points per sq. metre)

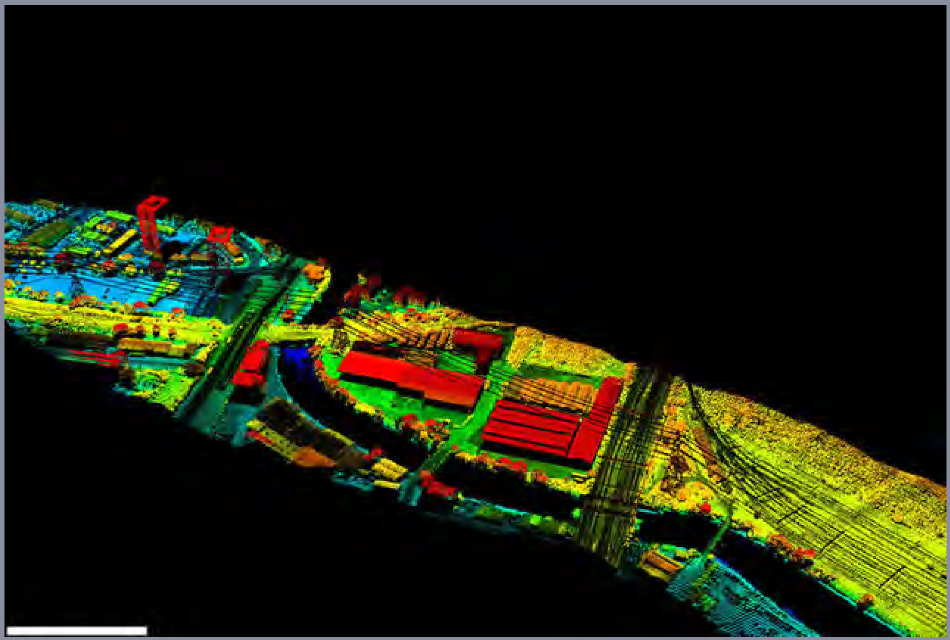


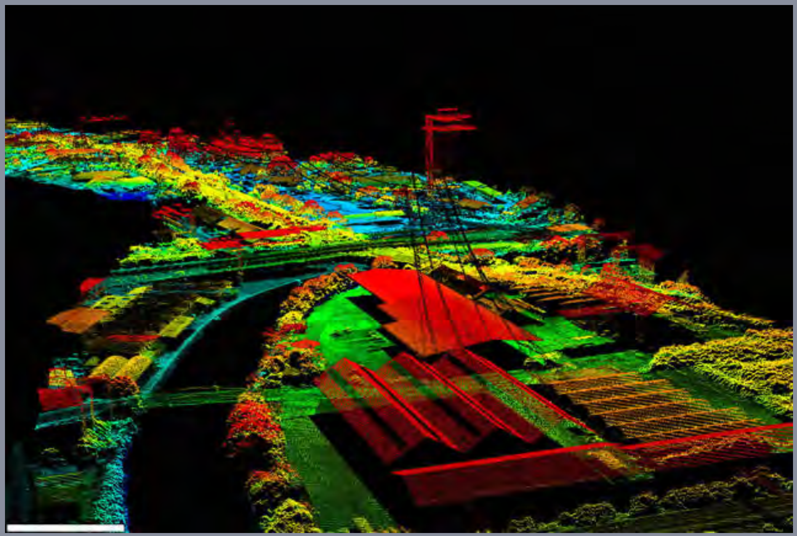
A24 – between Dorking and Reigate

Airborne Laser Scanning

ALS or Lidar = Light Detection and Ranging

Provides more detailed 'mapping' of the ground. Creates a ground shape or terrain model (DTM) plus (DEM) – top of the trees and buildings (or DSM)

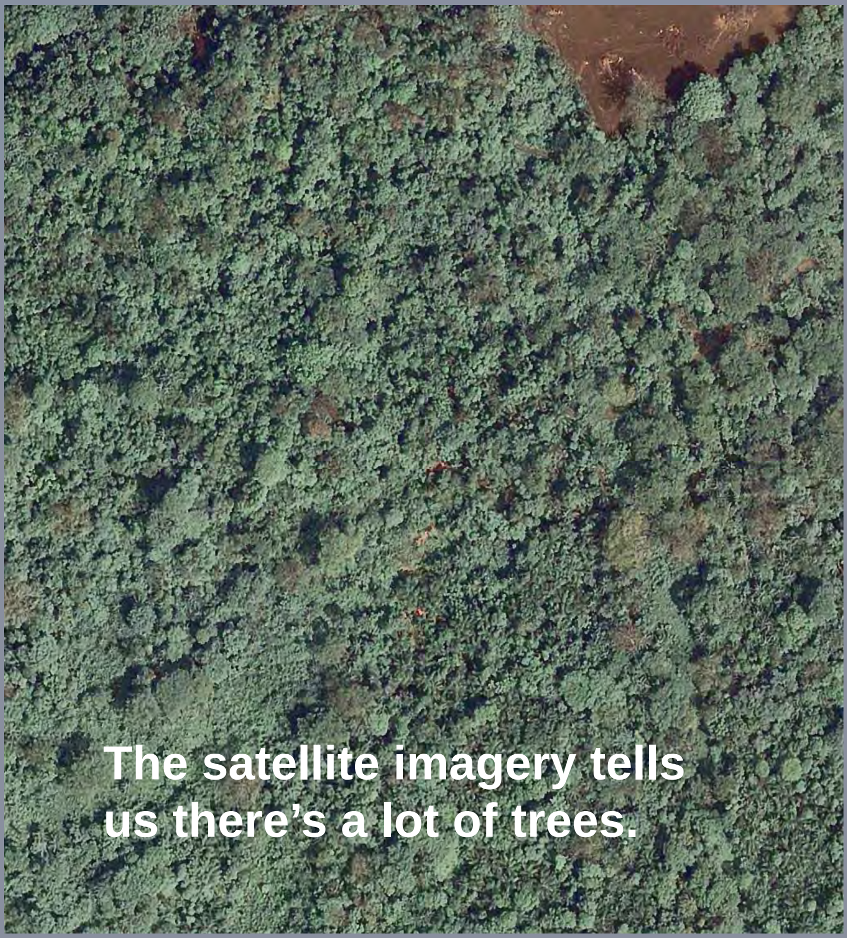


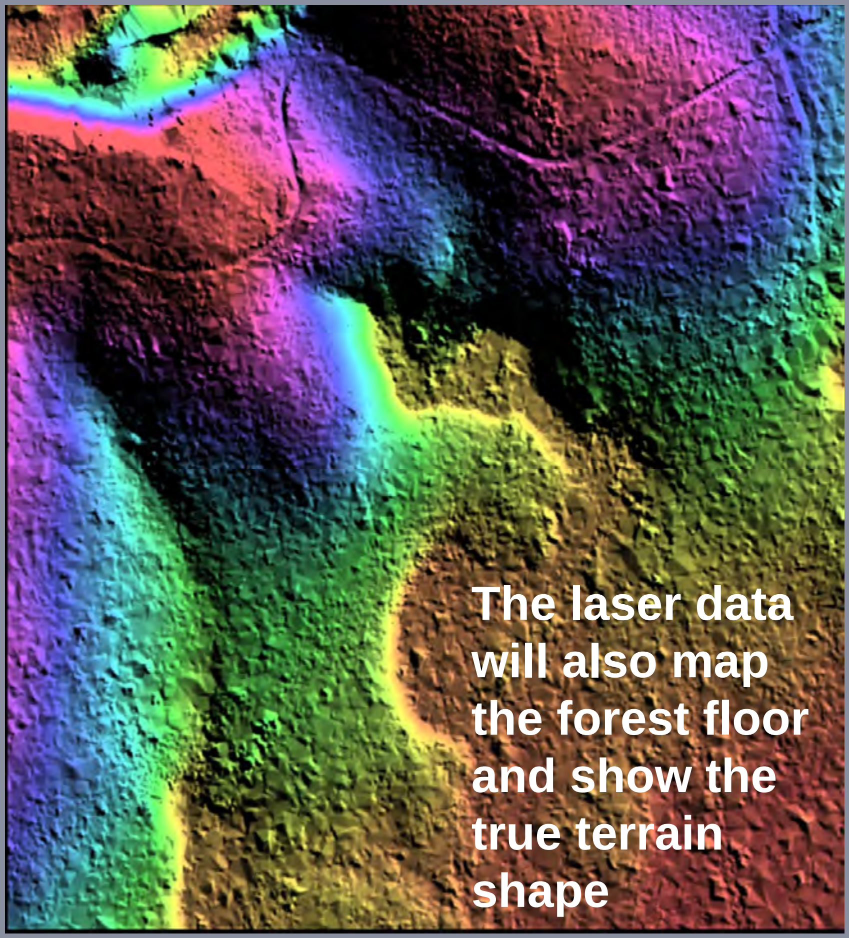


DEM = Digital elevation model – includes the tree tops
DTM = Digital terrain model – trees and buildings are removed

Image from Alberta Land Use Knowledge Network

For the forest / woodland Environment. 'First return' laser hit will map the forest canopy. But 'last return' laser hit will map the forest floor. The true terrain model.





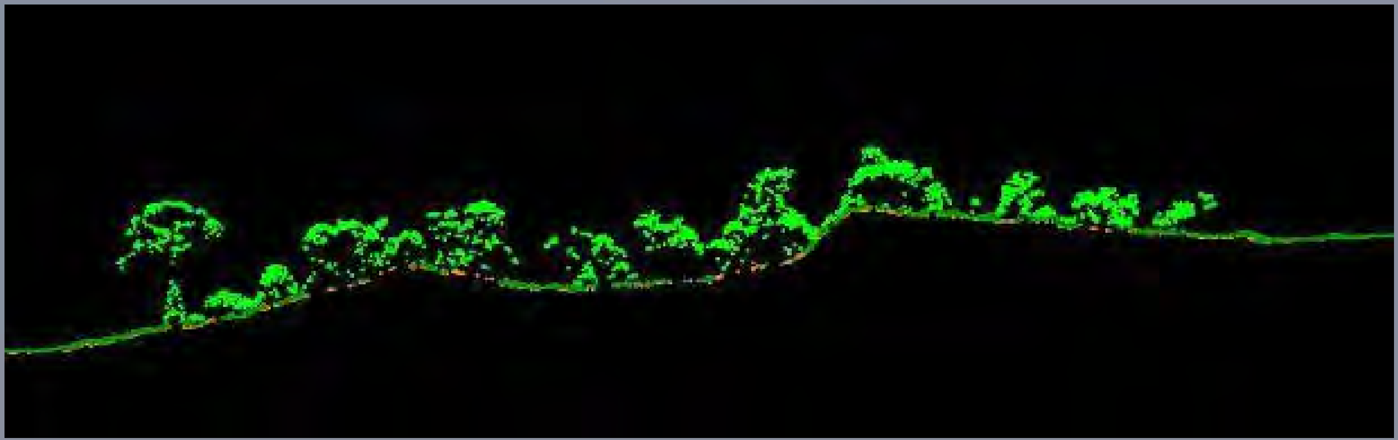
Example – Equatorial Guinea.

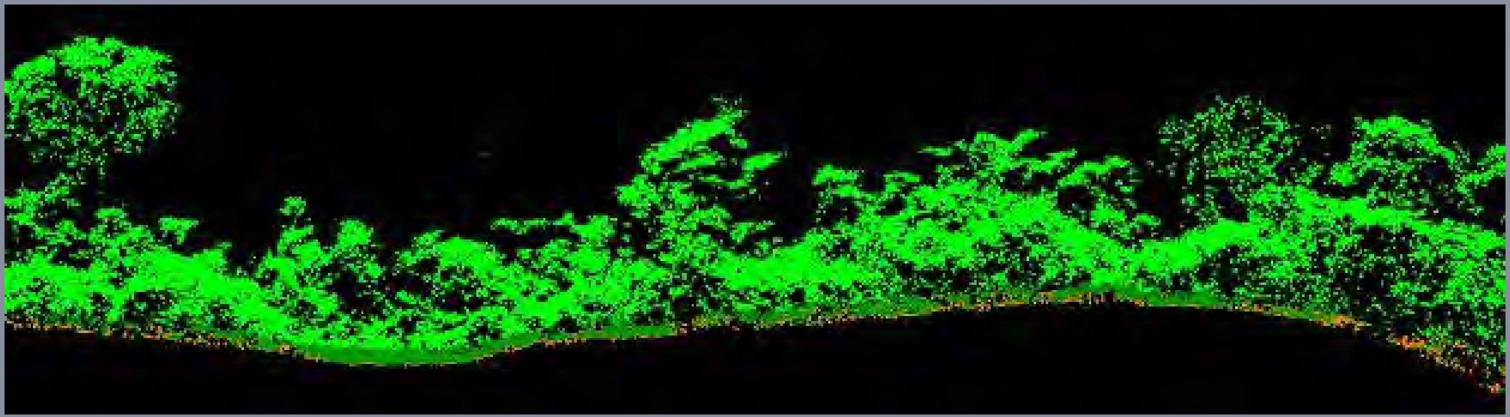
Survey for expansion of processing plant into adjacent dense rain forest.

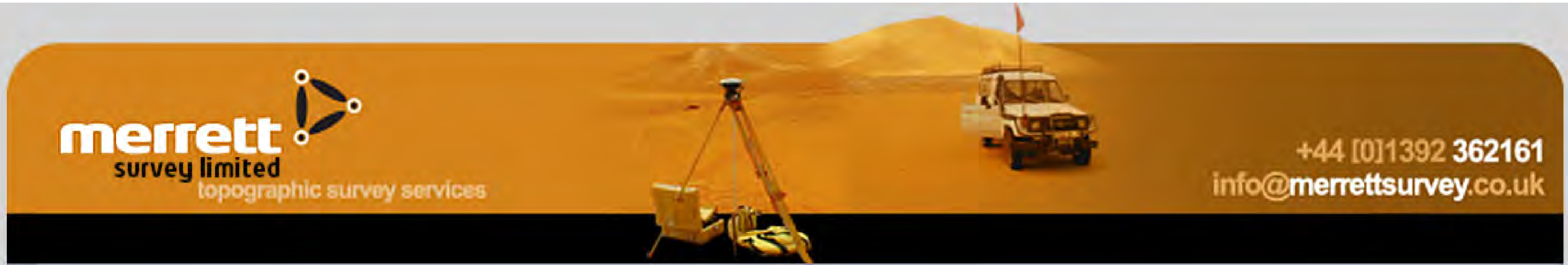
'Mapping' terrain through forest

GPS base station for the aerial laser mapping.

Detection of the forest floor and canopy using Lidar – Equatorial Guinea







Detection of the forest floor and canopy using Lidar

<u>**Possible applications for International Boundaries - Governments**</u>

Detection and accurate measurement of watersheds or rivers
(Where the boundary may be ‘defined’ by that watershed or river)

‘Sees’ through the forest – to map otherwise inaccessible terrain features.

‘Rights to water’ – potential disputes – looking at catchments.

Access planning – for a boundary demarkation project.

Resources mapping – can measure ‘biomass’ for carbon offset.

3D ‘visualisation’ of border regions – for presentation to Governments or Courts.

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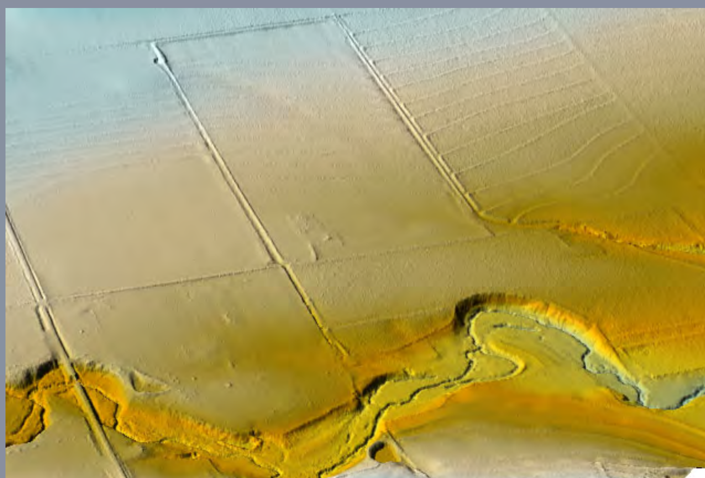
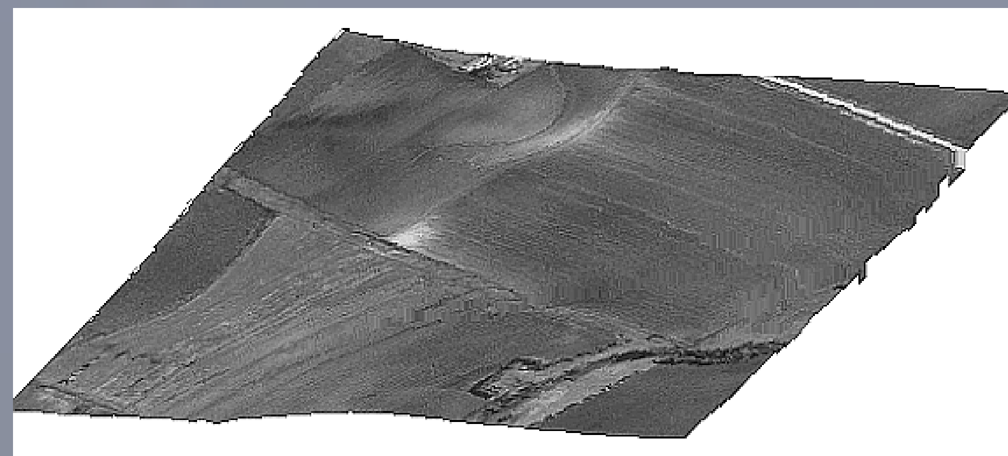
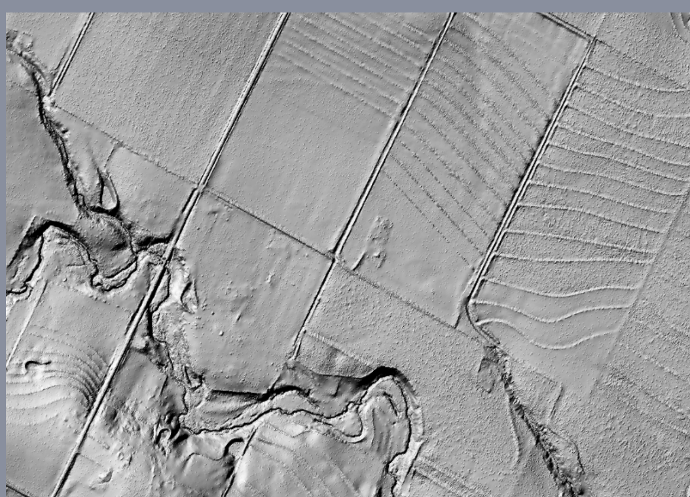
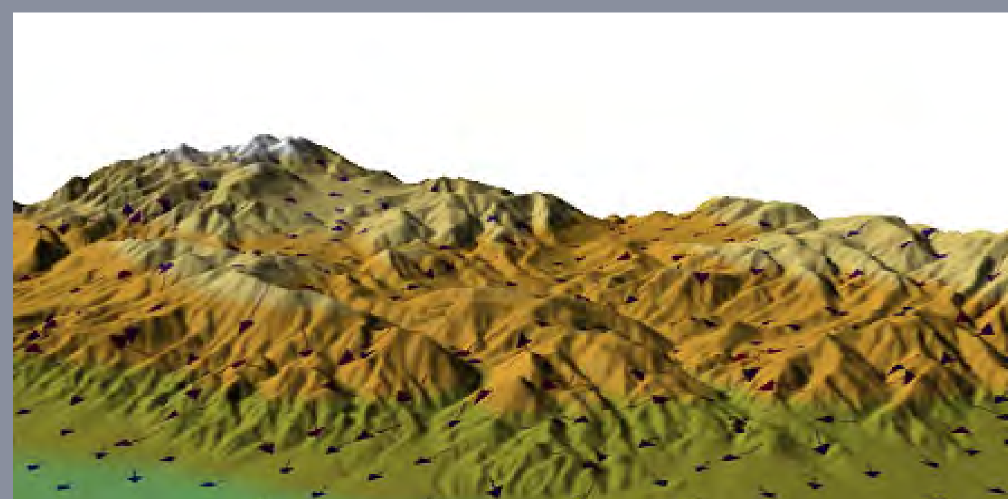
Different ways of presenting Lidar data





Hill-shaded to view relief and water (or oil spill) flow directions





Different ways of presenting Lidar data – coloured by height

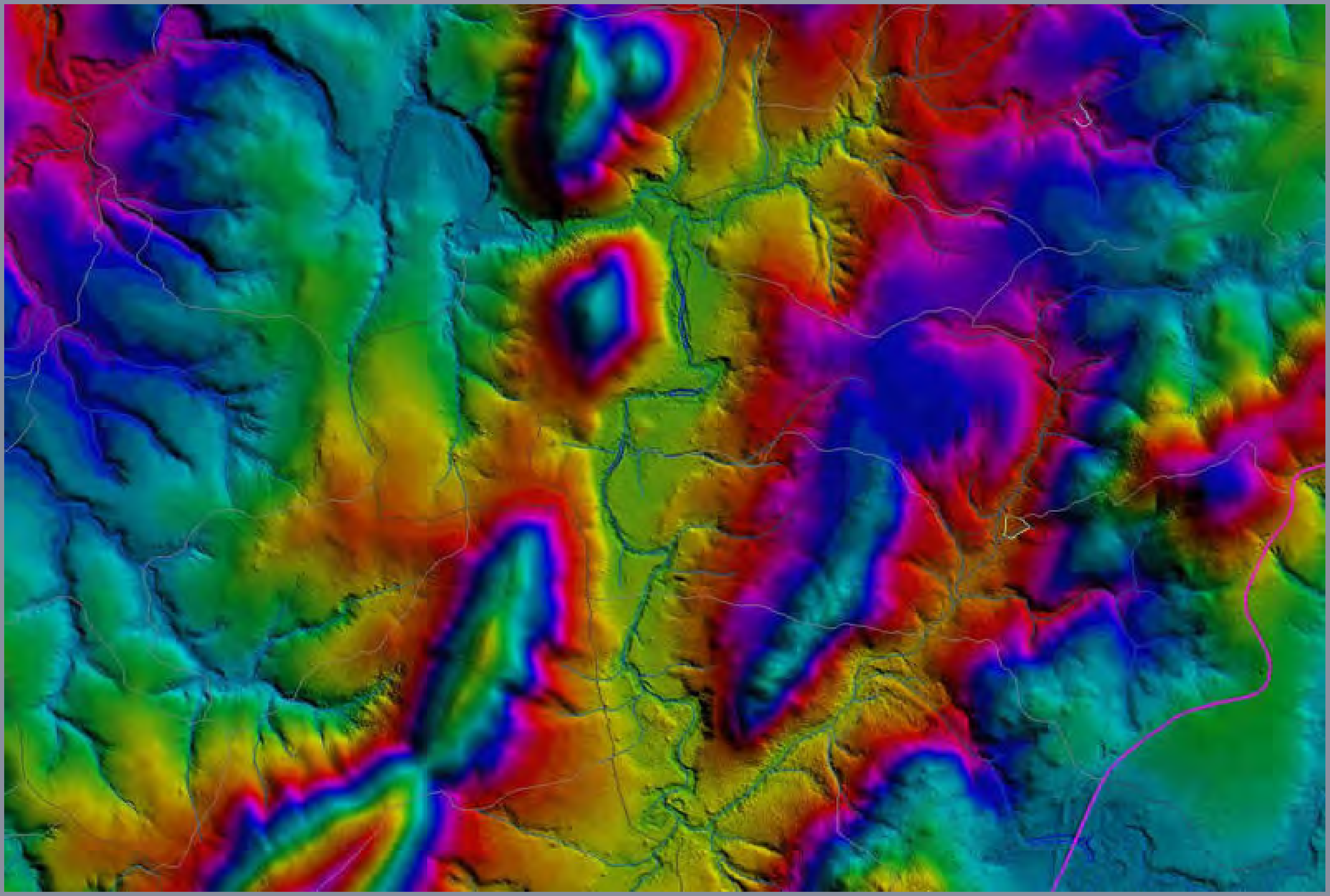
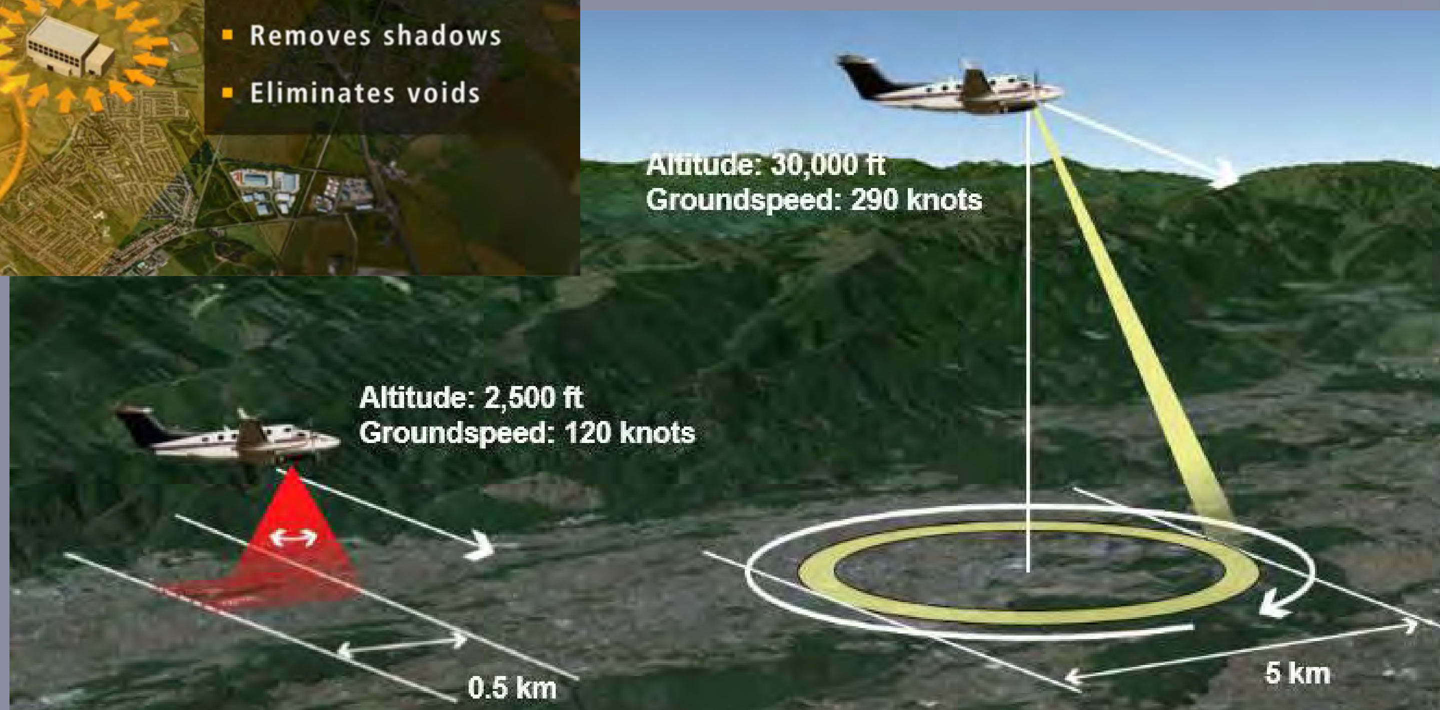


Image courtesy of Infoterra

Satellite imagery (Google Earth) of same area

STOP PRESS – Geiger Lidar

Fires from an ‘array’ and thus measures millions of points per second. Can survey 1000 sq km per hour.



For very large area Surveys (whole countries).

20 to 100 points per square metre.

Rotation of the laser ensures survey of ‘front’ and ‘back’ of objects on the ground.

Bathymetric Laser Scanning

Applications:-

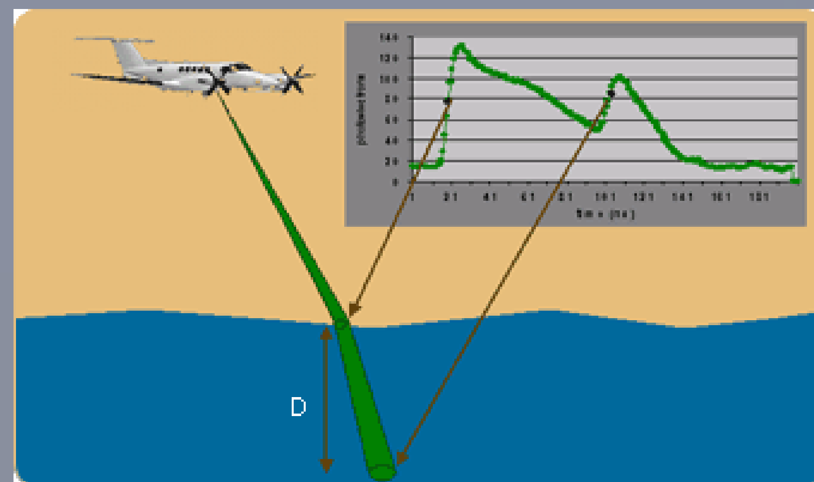
Uses a different wavelength laser

Penetration depends on turbidity of the water

So good for clear waters / near-shore / reefs

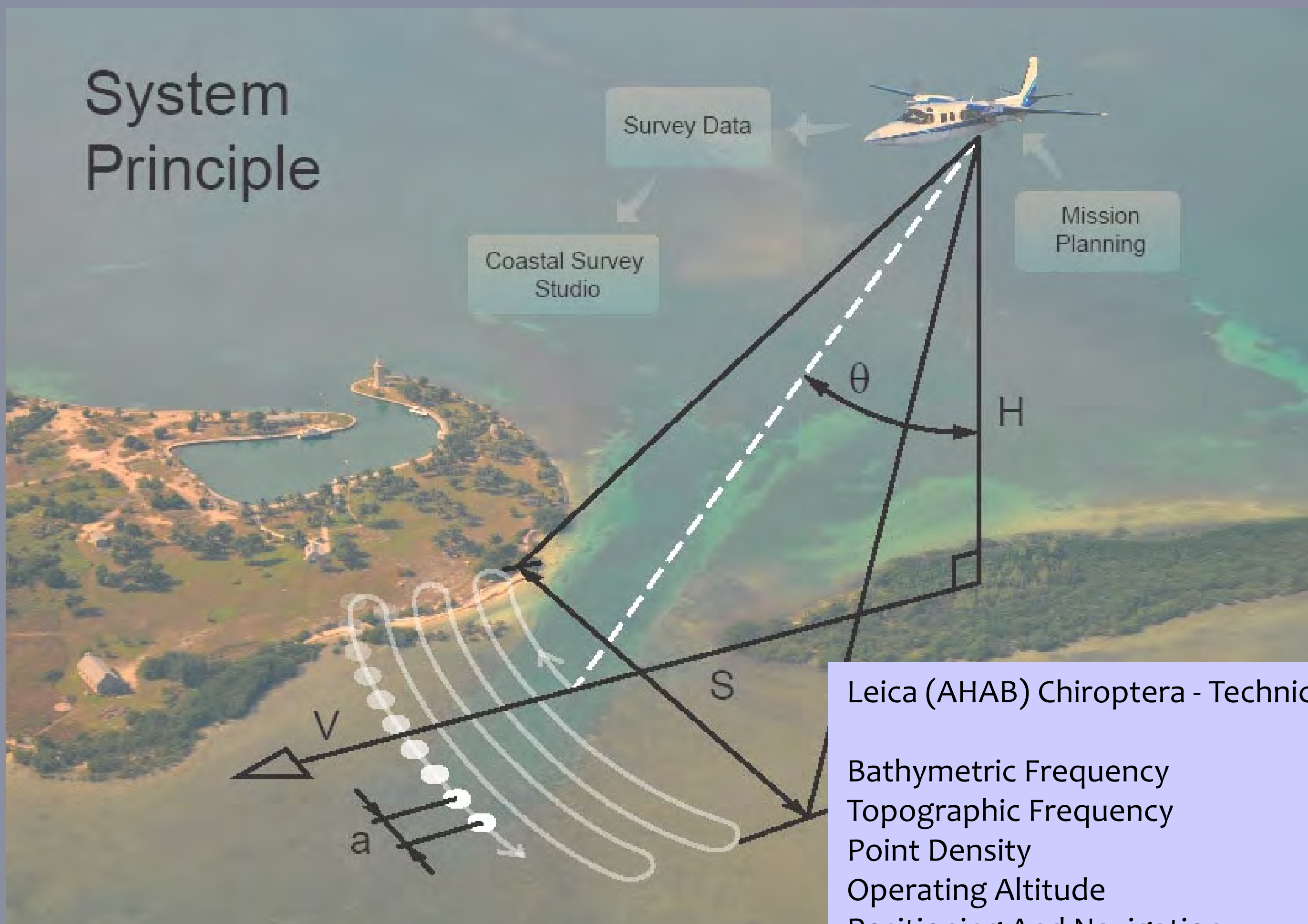
Only a few ‘players’ but more starting up

Only useable in shallow and clear waters (Unfortunately it won’t map a Continental shelf)



Images courtesy of Optech / Shoals

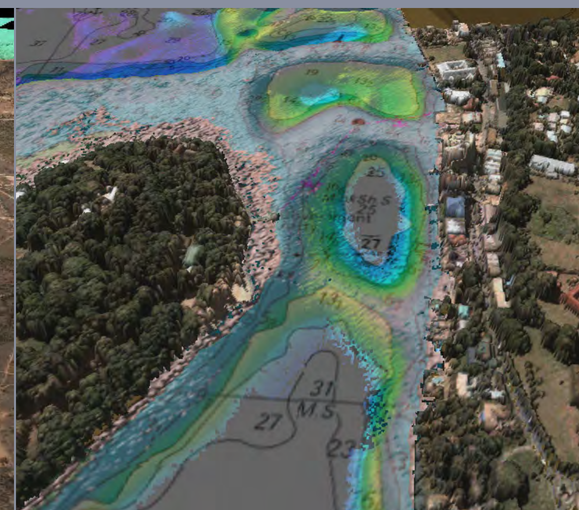
Bathymetric Lidar instruments use a different wavelength to penetrate the water

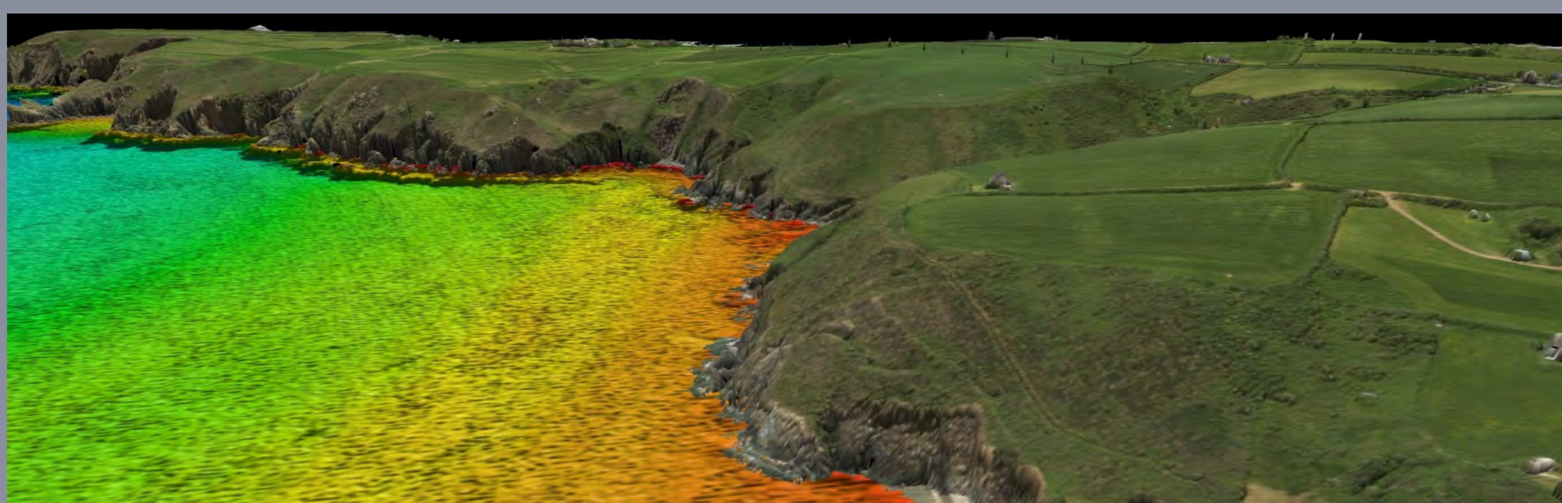


Leica (AHAB) Chiroptera - Technical Specification

Bathymetric Frequency	35kHz
Topographic Frequency	500kHz
Point Density	1.5pts m2 Hydro/12pts m2 topo
Operating Altitude	400m Hydro up to 1600m Topo
Positioning And Navigation	Novatel SPAN/LCI-100 IMU
Camera	Leica RCD 30 80MP RGBIR Camera
Depth Penetration	Up to 15m dependent upon turbidity

Bathymetric plus 'land' lidar and imagery combined





Satellite based remote sensing

We are entering a new era of satellite deployment. Earth oberservation (EO) is becoming a 'fundamental infrastructure'

Multiple micro satellites will provide daily updates of any location

Provides imagery and now video

More affordable and much better resolution

Resolution examples	**Geoeye**	**0.46m res.**	**4 Band**
	World View	**0.46m res**	**15 band**

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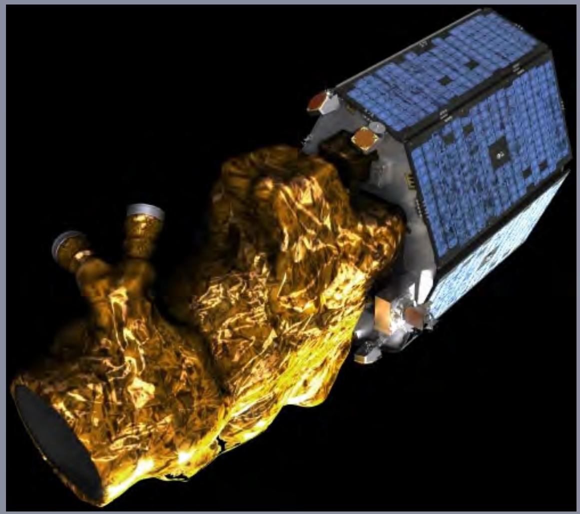
Satellite based remote sensing

Earth-i 'Small' UK Company launching new breed of satellites

Example of 'daily' observation (any point on the Earth's surface can be re-surveyed daily.



Earth- i - DMC3/TripleSat Constellation

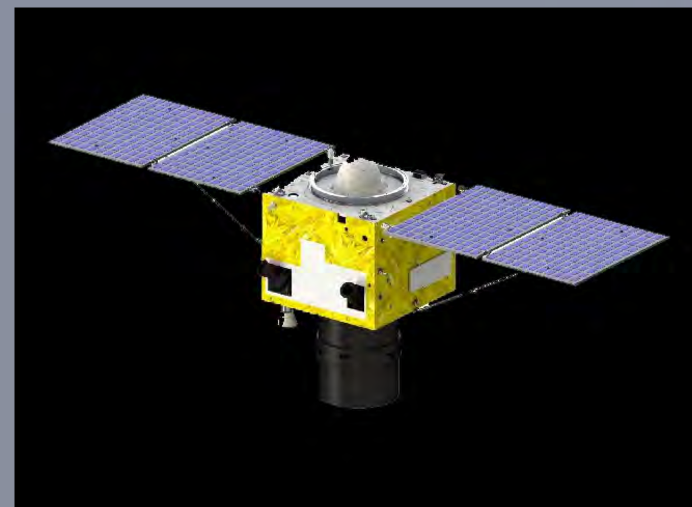
Satellite Constellation 3 identical optical satellites

Resolution 1m, 80cm pixel size
Revisit Daily
Bands Multispectral RGB, near infrared & panchromatic
Orbit 651km / 1030 sun synchronous orbit
Swath Width ~23km
Image file format GeoTIFF/TIFF

Satellite based remote sensing

Earth-i 'Small' UK Company launching new breed of satellites

Example of very high resolution and
Earth's surface visited every 2 days



SuperView Constellation

Satellite Type: Optical
Resolution: 40cm
Orbit: Sun Synchronous, altitude of 530km
Revisit: 2 days
Spectral Bands: Panchromatic and 4 band multispectral
Swath Width: 12km

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Example of new video capture

Vivid-i Constellation

- 15 satellites being launched over 3 years (first one in orbit now)
- Twice daily revisit
- 1m resolution full colour video
- Orbit – 500 km
- Image view 5.2 x 5.2 km

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UAV – Drone technology Now becoming very practical

Suggestions for possible boundary work:-

Monitoring of boundaries / security / infringements

Mapping of catchments – large drones can carry lightweight lidar instruments and can fly for many hours BVLOS (beyond visual line of sight)

Problems with Civil Aviation and military permissions

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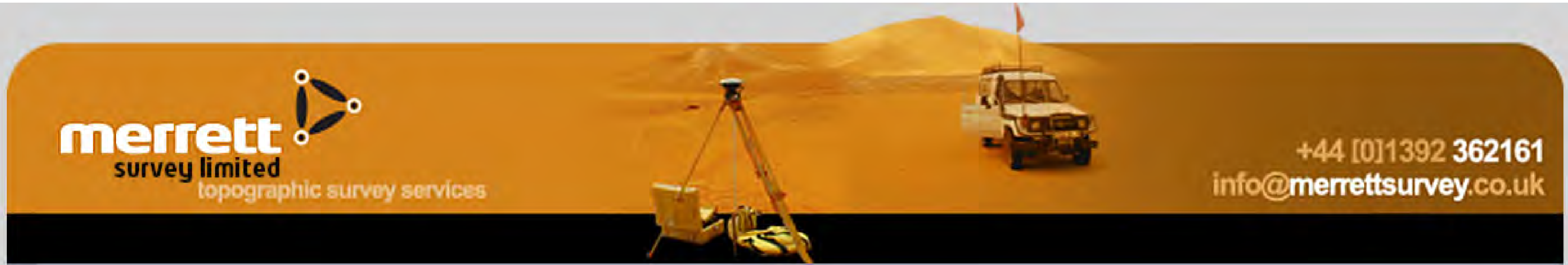
<u>UAV – Drone technology</u>

Prion Mk3 from UAVE Limited

Wingspan.. 3.8m
Length... 3.0m
Weight (configured for surveys)......................... 27kg
Fuel capacity... 7lts
Fuel consumption (cruising)................................ 0.5lts/hr
Cruising speed (for surveying)............................. 80kph
Operational range... 1000+km
Payload... optimal 10 kg, maximum 15 kg
Engine... 120cc 4 stroke petrol



Useful Links

Geodetic datums

http://www.colorado.edu/geography/gcraft/notes/datum/datum_f.html

International Earth Rotation Service

http://www.iers.org

Lidar and other remote sensing methods

Helpful series of instructional videos from Alberta Govt. Canada
http://www.youtube.com/watch?v=Utg_jHiPIpA&feature=youtu.be

Use of Lidar and long range UAV for carbon inventory (forests)
https://www.carbomap.xyz/

New satellite era technology
http://earthi.space/

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Thank you for listening to:

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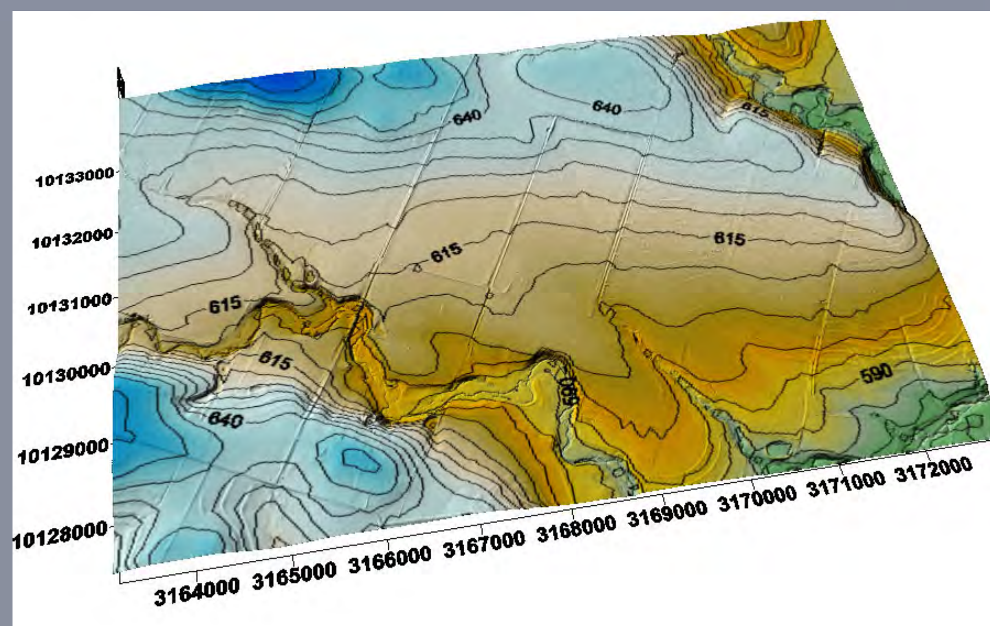

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