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Development of a Satellite Tracking Ground Station for the nSight-1 CubeSat Mission

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Acknowledgements

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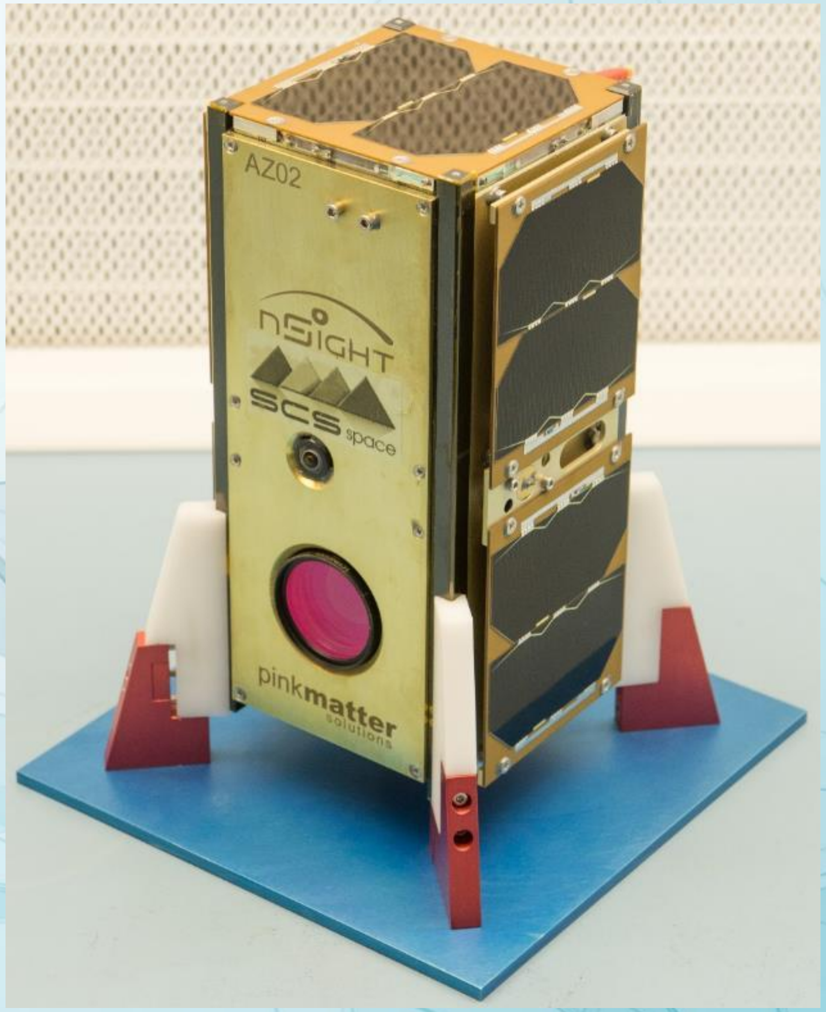
- Dr Lourens Visagie – University of Stellenbosch
- Hendrik Burger – SCS Space

Introduction

- Overview of the nSight-1 mission
- Development of a ground station for nSight-1 mission
  - Amateur radio frequencies in VHF and UHF bands
- Software
- nSight-1 images

nSight-1 Mission Overview

- Built by SCS-Space in South Africa
- Late entry to QB50 – nSight-1 project started in 2016
- QB50: constellation of Cubesats, which is coordinated by the Von Karman Institute for Fluid Dynamics (VKI) in Belgium
- Gather science data in the lower thermosphere
- Launched to the International Space Station on 18 April 2017, together with 27 other CubeSats and successfully deployed into a 400km low-Earth orbit on 25 May 2017



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nSight-1 Mission Overview

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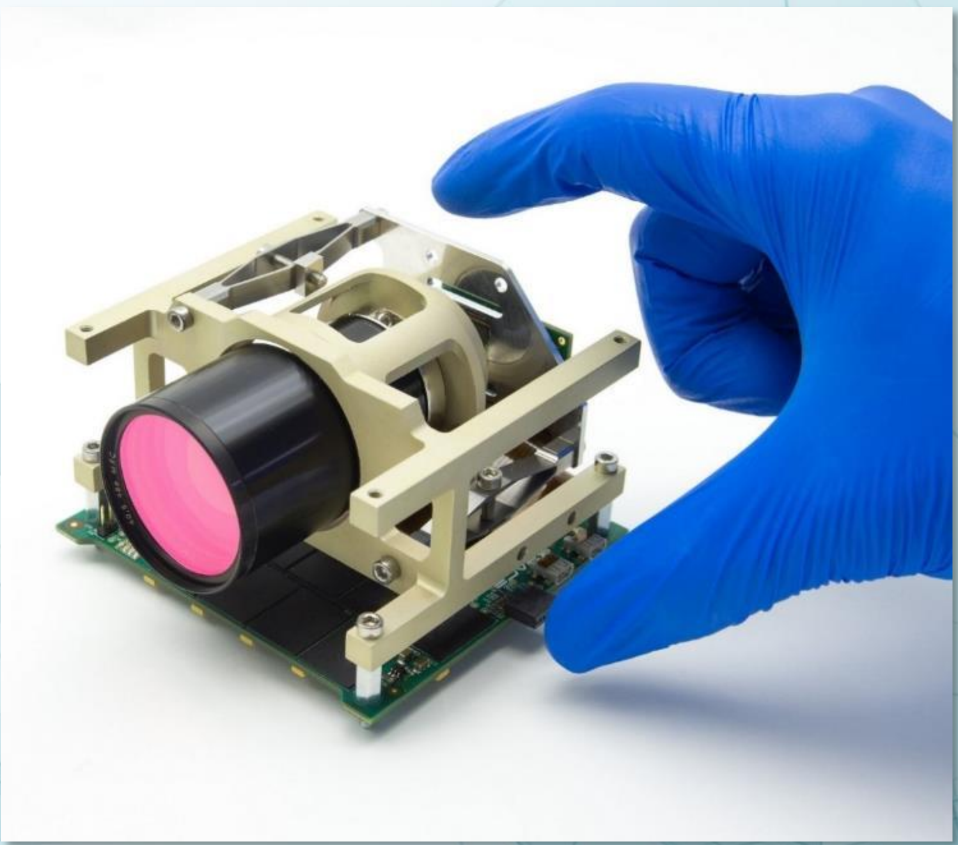
- Testbed for in-house developed "Gecko" Earth imager
- Very short development schedule
- COTS sub-systems used where possible
- Borrowed from partners – CubeSpace, Stellenbosch University, Spaceteq



nSight-1 Mission Overview

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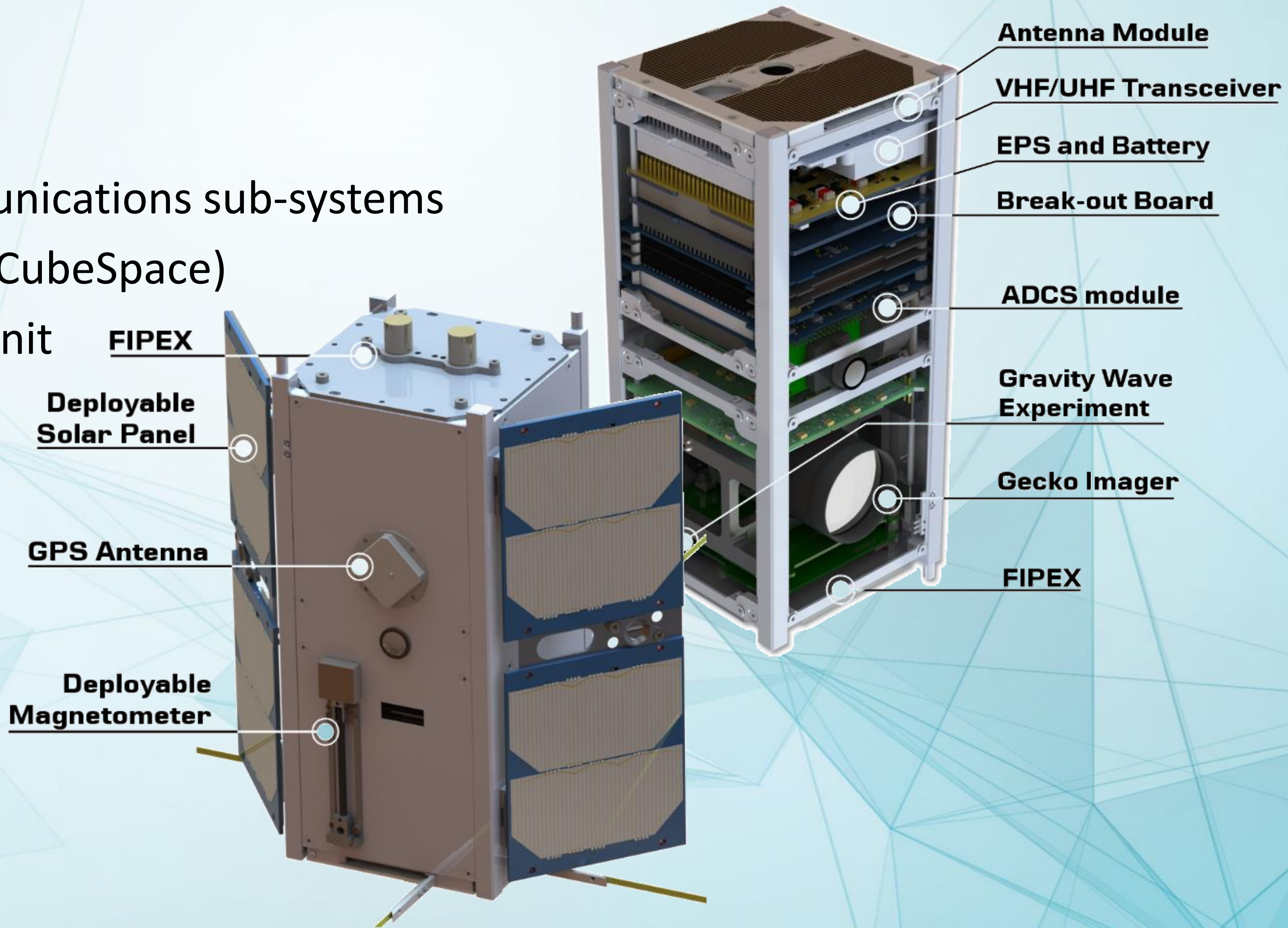
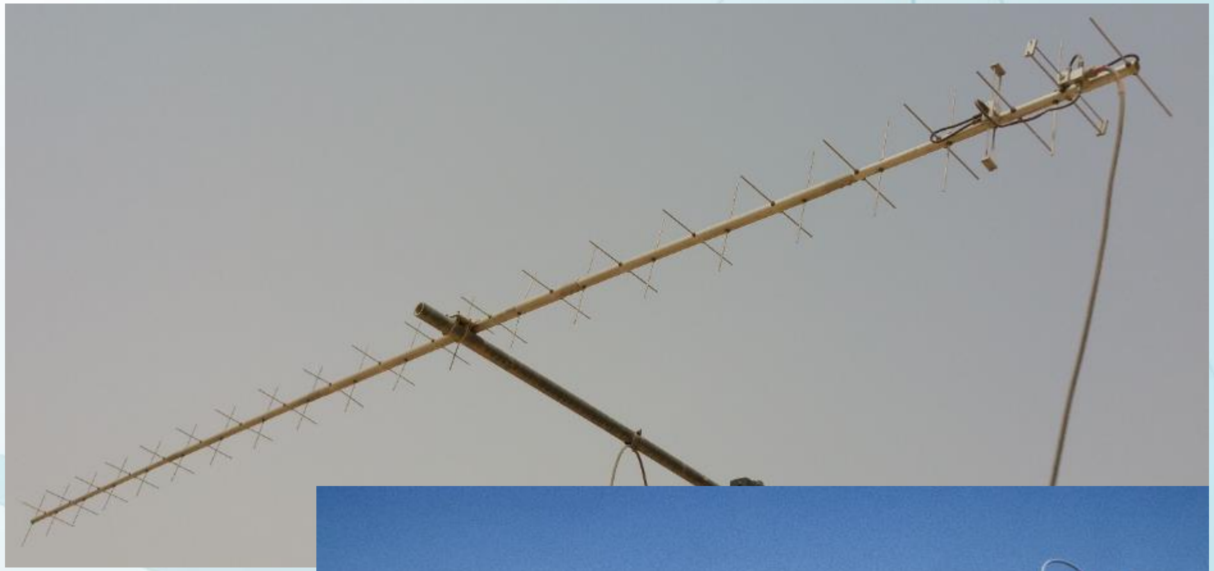
- COTS EPS and Communications sub-systems
- Y-momentum ADCS (CubeSpace)
- QB50 FIPEX science unit
- Gecko Imager



Ground station design

- Link budget
  - Determine performance parameters of the ground station
- Typical Cubesat ground station requirements
  - Antenna type
    - Yagi antennas for VHF and UHF bands are typical
    - Helical antennas are also used
    - For S-band and higher bands, parabolic antennas are typically used



Typical requirements

- Antenna gain
  - Circular polarisation advisable
  - Typical gain at VHF is 12 dBic, and at UHF 16 dBic
- Antenna size
  - Antennas can be 3 to 6 m long.
- Antenna pointing
  - Rotator must be selected to carry the weight and angular momentum
- Environmental factors
  - Wind loading, dust, temperature extremes, water, ice, baboons

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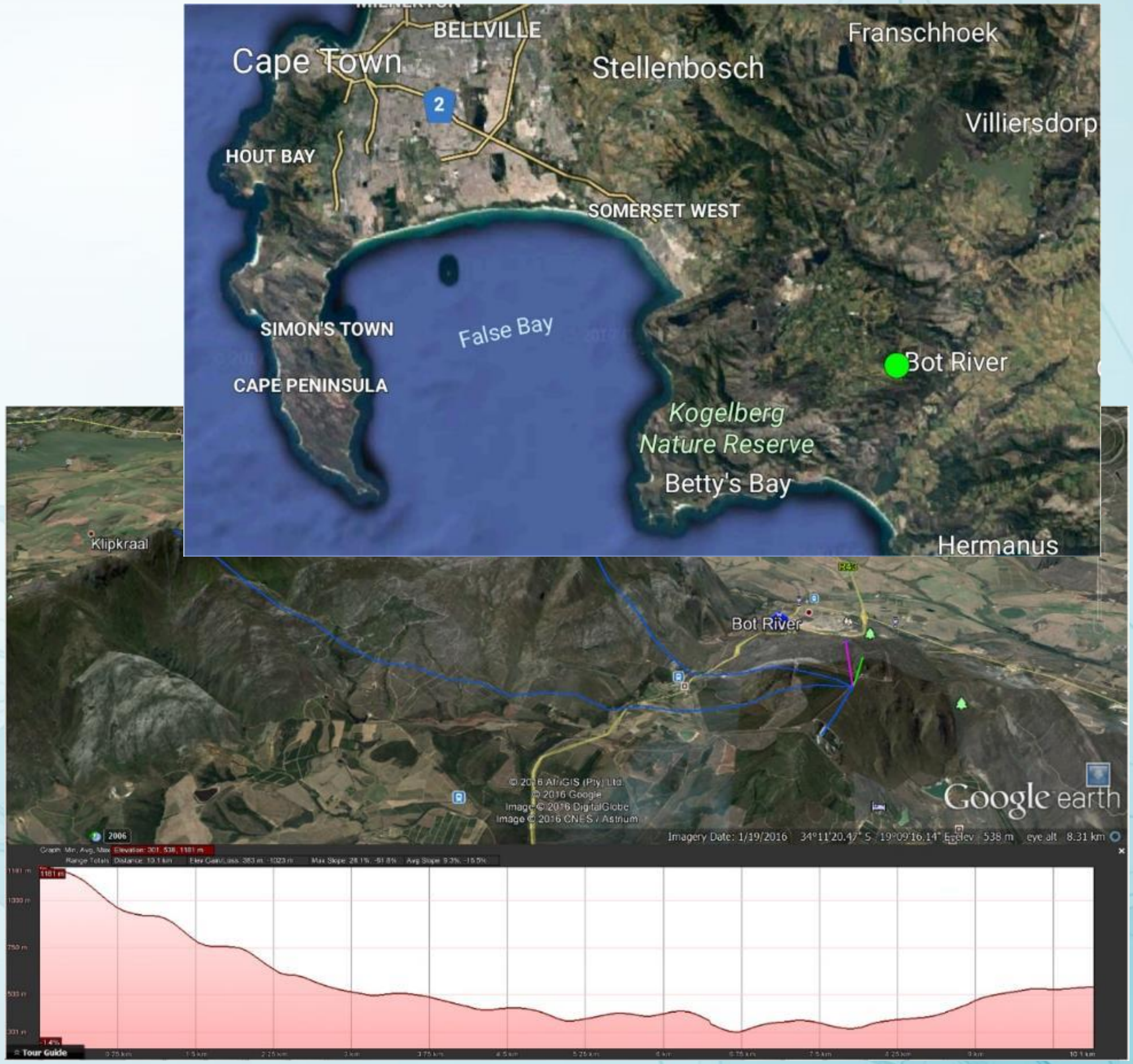
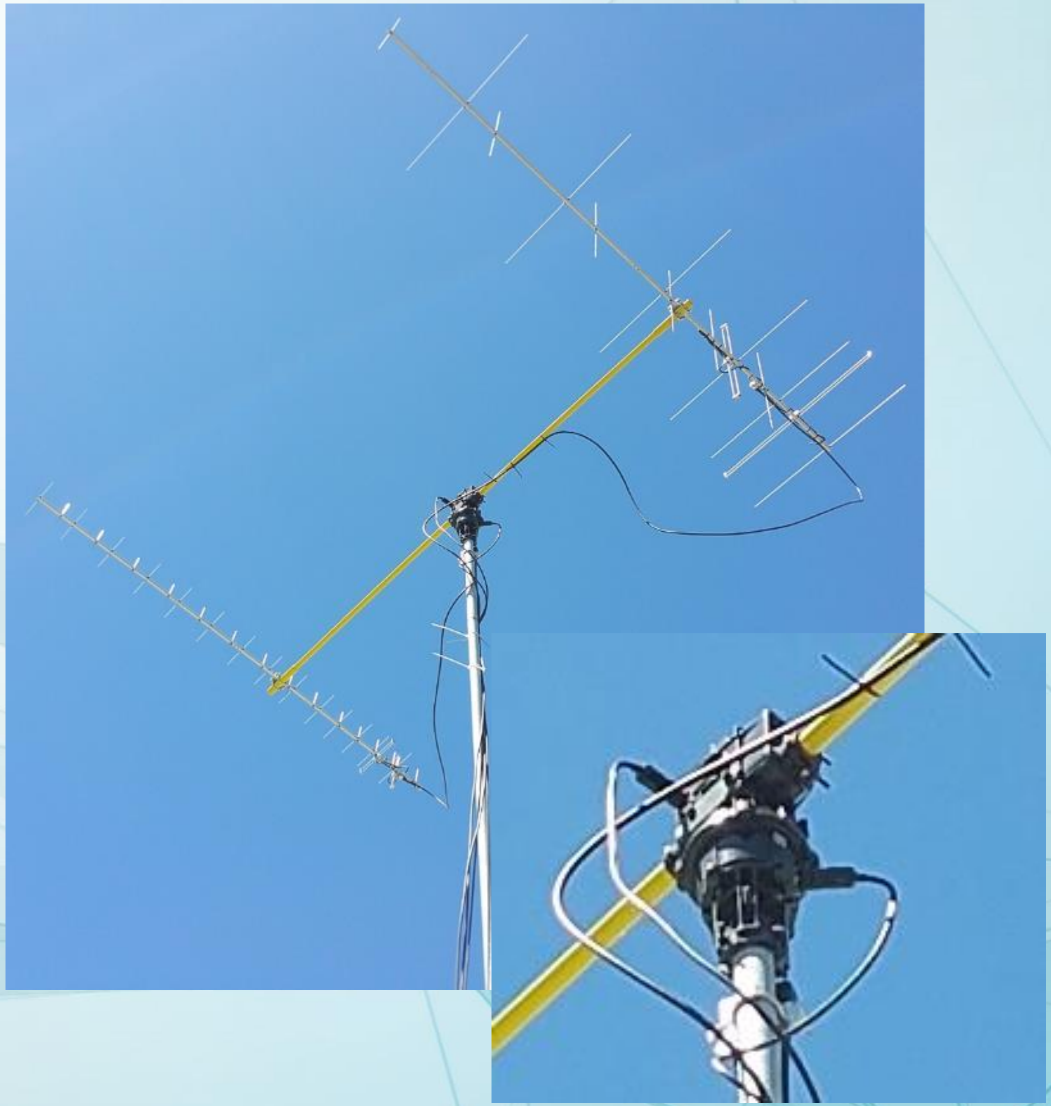
GS location

- Selecting a site
  - Select for a low horizon, obscuration by buildings, other antennas or objects
  - Low radio interference levels
  - Access to services
    - Electricity
    - Networking
- Surveying the horizon
  - Google Earth useful for this
- Location selected in Houwteq complex near Grabouw, South Africa



Outdoor hardware

- Antennas
- Rotator
  - LEO satellites move quickly with respect to the ground station
  - Antennas must be pointed at the orbiting satellite
  - Pointing angles adjusted in the vertical (elevation) and horizontal (azimuth) directions
  - Therefore two motors needed



Outdoor hardware

- Cables
  - Coaxial cable for each antenna
  - Control cable for each rotator
- Mechanical construction
  - Mast / tower
  - Cross-boom to mount multiple antennas to the same rotator

Indoor hardware

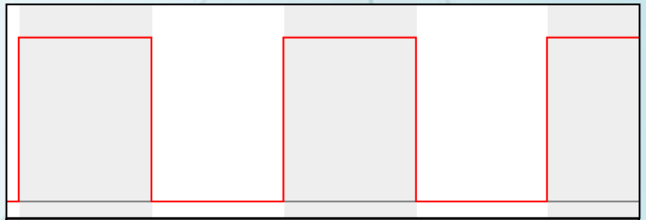
- Radio transceiver
  - Transceiver must support the frequencies of operation
  - Doppler shift of signals due to relative motion of satellite.
    - Max ±3 kHz at 145 MHz, ±10 kHz at 436 MHz
  - Frequency step size < 1 kHz to allow for Doppler compensation
  - Usually control radio functions through PC serial port
  - Audio (Tx and Rx) from radio are connected to modem device
  - Built-in power amplifier or external.
    - Typically 50 W to 100 W depending on antenna gain

Indoor hardware

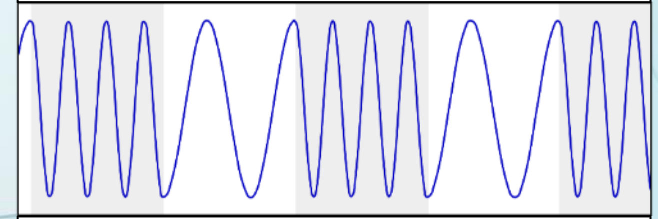
- Icom IC-9100
  - Meets all requirements
  - Works in amateur bands. Need different radio for commercial bands
  - Single USB interface used for CI-V control as well as baseband transmit and receive audio
- Funcube dongle
  - USB flashdrive sized software defined radio receiver
  - Used to record audio of all communication with the satellite

Modems

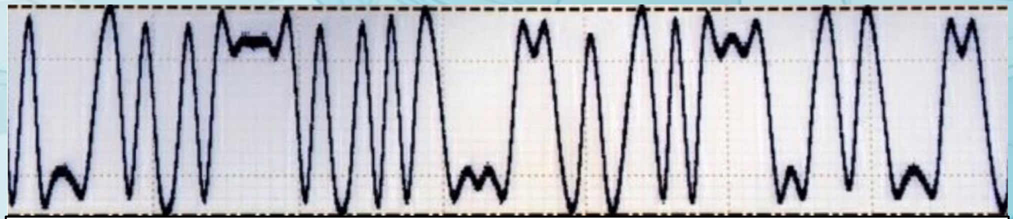
- Can either be a hardware TNC or a PC software application that converts data to baseband audio and vice versa
- Typical modulation schemes used are
  - 1.2 kbps AFSK (Bell 202 modem std): two audio tones represent 1's and 0's
  - 9.6 kbps and higher GMSK or G3RUH modem: filters rectangular pulses with digital pulse shaping filter – limit bandwidth without introducing ISI
  - Both the above are applied as baseband audio signals to the radio transmitter and frequency modulated onto an RF carrier by the radio.



Binary signal



AFSK Modulated signal



Gaussian filtered baseband signal for GMSK

Modems

- Other modulation schemes include digital modulation (BPSK or QPSK)
  - I and Q data streams are pulse shaped and IQ modulated onto a low IF to create baseband audio signal. This is then shifted up to the transmit frequency by the radio using SSB modulation
  - Alternatively, a Software Defined Radio (SDR) with external RF front end (LNA and PA) can be used to transmit and receive various modulation and coding schemes

Rotator control and PC interface

- Yaesu G-5500 rotator provided with a controller to allow manual positioning of the antennas in azimuth and elevation.
- An external control interface is provided, but a PC interface is needed to connect to a serial port.
- Controller provides voltage feedback of both azimuth and elevation rotators
- PC interface must be calibrated to relate these voltages to actual azimuth and elevation angles

Rotator control and PC interface

- Various products are available
  - Yaesu GS-232A
  - Cheaper alternatives available such as ERC-M and EA4TX ARS-USB
    - Allows calibration and linearisation of the voltage input to angular output of the rotator
    - USB interface to PC
- PC
  - To run mission control software and modems, as well as control hardware

Software

- Time-keeping
  - Elevation angle rate for a 500 km orbit is 0.05°/s near the horizon, but increases to about 0.9°/s at zenith. Satellite quickly travels out of narrow beam of a high gain antenna
- Ephemeris updates
  - A.k.a. Keppler parameters or Two Line Elements (TLEs)
  - Drifts over time. Must be updated regularly from Celestrak.com
  - Or create own from GPS on-board satellite

Software

- Telecommand and Telemetry Software Interface
  - Implements satellite’s communications protocol
  - Packet structure
  - Telecommands and telemetry interfaces incl definitions and parameters
  - File transfer protocol

Software

- Amateur radio software
  - Rotator and radio control facilitated through serial (COM) ports
  - Hamlib for rotator and radio control
    - Radio transceiver control
      - CI-V command set over USB or serial to CI-V interface
    - Background service providing standardised library to control radio equipment.
    - Listens for commands at IP address:port, interprets and translates to equipment’s native command set and writes to equipment’s registered serial port

Software

- Amateur radio software
  - GPredict
    - Satellite tracker and orbit propagator
  - MixW
    - Multi-mode software modem

Software

- Custom software
  - CubeSpace CubeMCS
    - Application connects to modem serial port
    - Implements complete TT&C interface to satellite
    - Includes pass automation features

Command and Telemetry Interface

- XML file – defines command and telemetry interface
- Generate flight software source code from XML interface definition
- Generate ground software source code (classes) and also user interface elements from XML interface definition
- Changes to interface occur only in one place (the XML markup) – eliminates the possibility of “copy and paste” errors

```
  <Ttcs CanSet="false" CanGet="true" CodeName="PositionLLH" DisplayName="Satellite Position (LLH)"
Description="Satellite position in WGS-84 coordinate frame" Len="6" >

      <Item CodeName="Latitude" DisplayName="Latitude" Description="WGS-84 Latitude angle " BitOffset="0"
BitLength="16" ValueType="SignedInteger" CalibrationUserToRaw="USERVAL*100.0"
CalibrationRawToUser="RAWVAL*0.01" MeasurementUnit="deg" />

      …

  </Ttcs>
```

Satellite Position (LLH)		
Latitude	-16.93	deg
Longitude	23.40	deg
Altitude	400.79	km

Wheel Speed		
X Wheel Speed	0	rpm
Y Wheel Speed	-4709	rpm
Z Wheel Speed	0	rpm

PositionLLH | 151 | 30 | Satellite Position (LLH) | Satellite position in WGS-84 coordinate frame | ADCS State | 6 | part of AdcsState

Bit Offse	Bit Len	Name (source code)	Display Name	Description	Value Type	Enumeration	Calibration (User to Raw)	Calibration (Raw to User)	Unit
288	16	Latitude	Latitude	WGS-84 Latitude angle	SignedInteger		RAWVAL*0.01	USERVAL*100.0	deg
304	16	Longitude	Longitude	Longitude angle	SignedInteger		RAWVAL*0.01	USERVAL*100.0	deg
320	16	Altitude	Altitude	WGS-84 altitude	UnsignedInteger		RAWVAL*0.01	USERVAL*100.0	km

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Software

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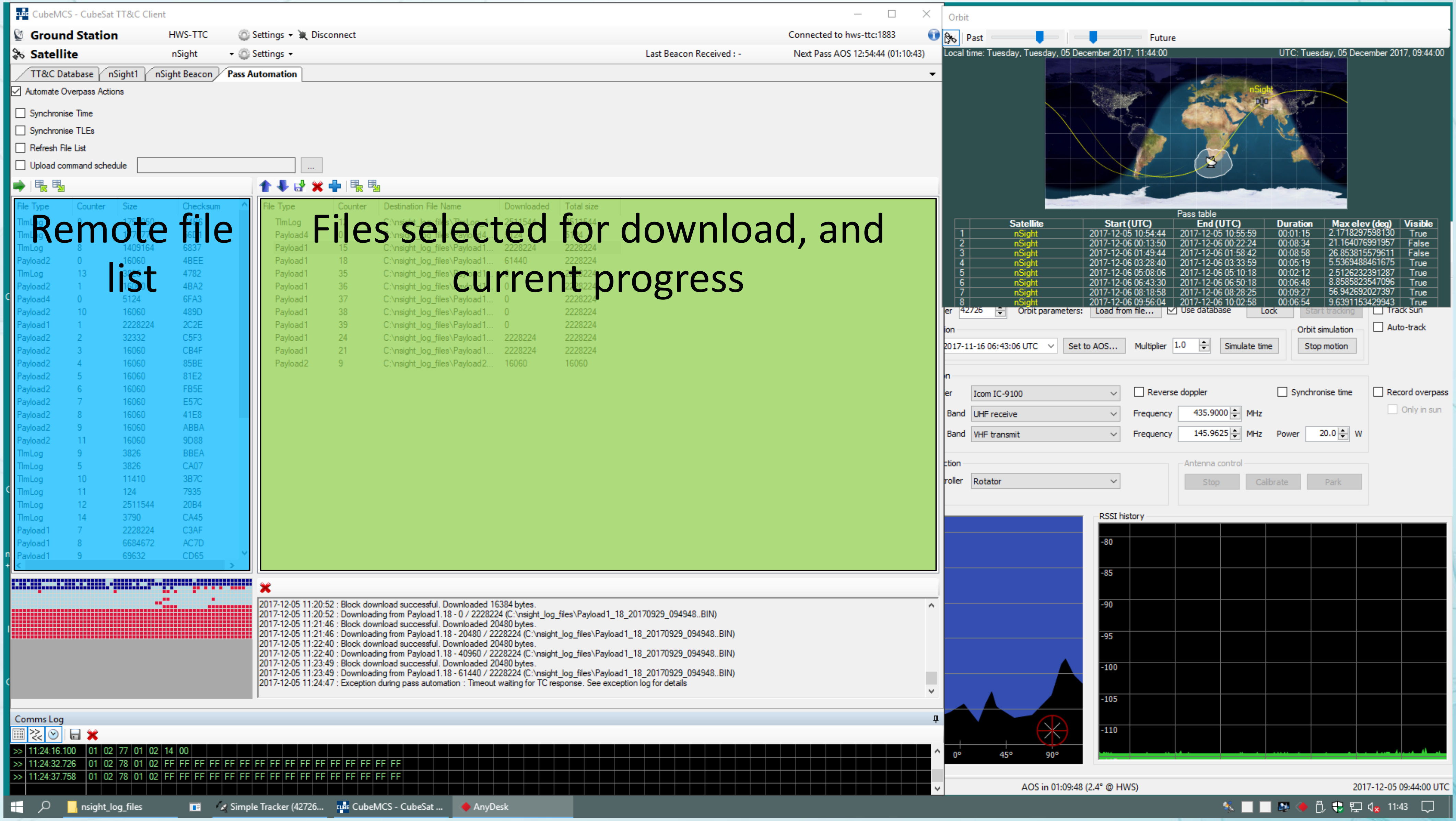
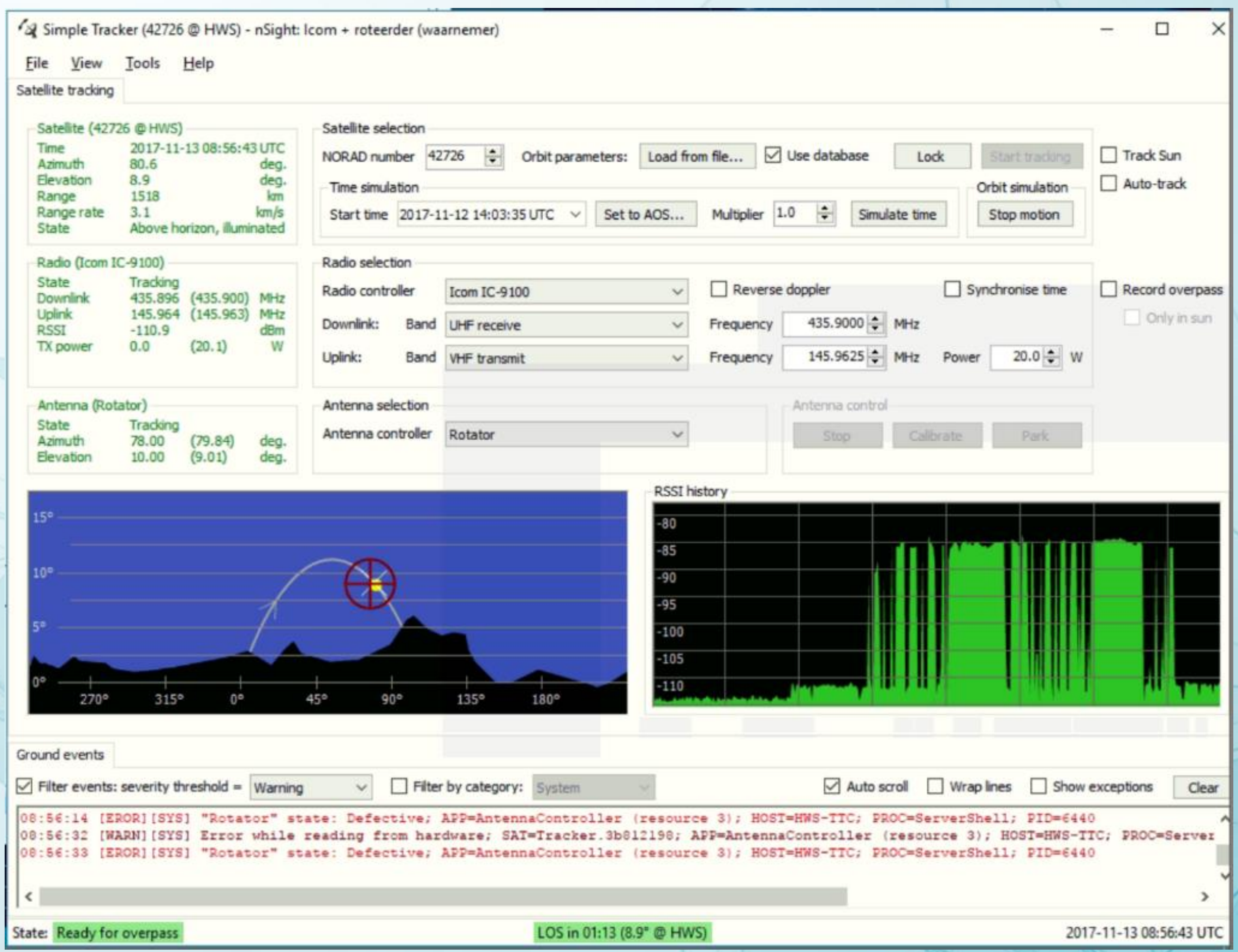


- COTS software
  - Denel Spaceteq KissTNC app / service
    - Modem daemon hooks onto soundcard device on one side and serial port on the other
  - Denel Spaceteq MCS
    - Complete Mission Control Software suite
    - Controls hardware
    - Orbit propagator
    - Maintains history log of all communications
    - Visualise historical data



Cost

- Using COTS components is not cheap, but development of own equipment generally not feasible
- All equipment imported, except mast, boom, cables and miscellaneous mechanical parts. Shipping and customs duties add to cost.
- Basic VHF/UHF station between $4k and $10k

Common issues

- Cables – mechanical stress
  - Movement of antennas can cause cable connector joints to fail
- Waterproofing – water gets in everywhere
  - Use outdoor waterproof cable and apply sealant to all electrical connections
- Getting amateur radio software applications to work together

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California, USA

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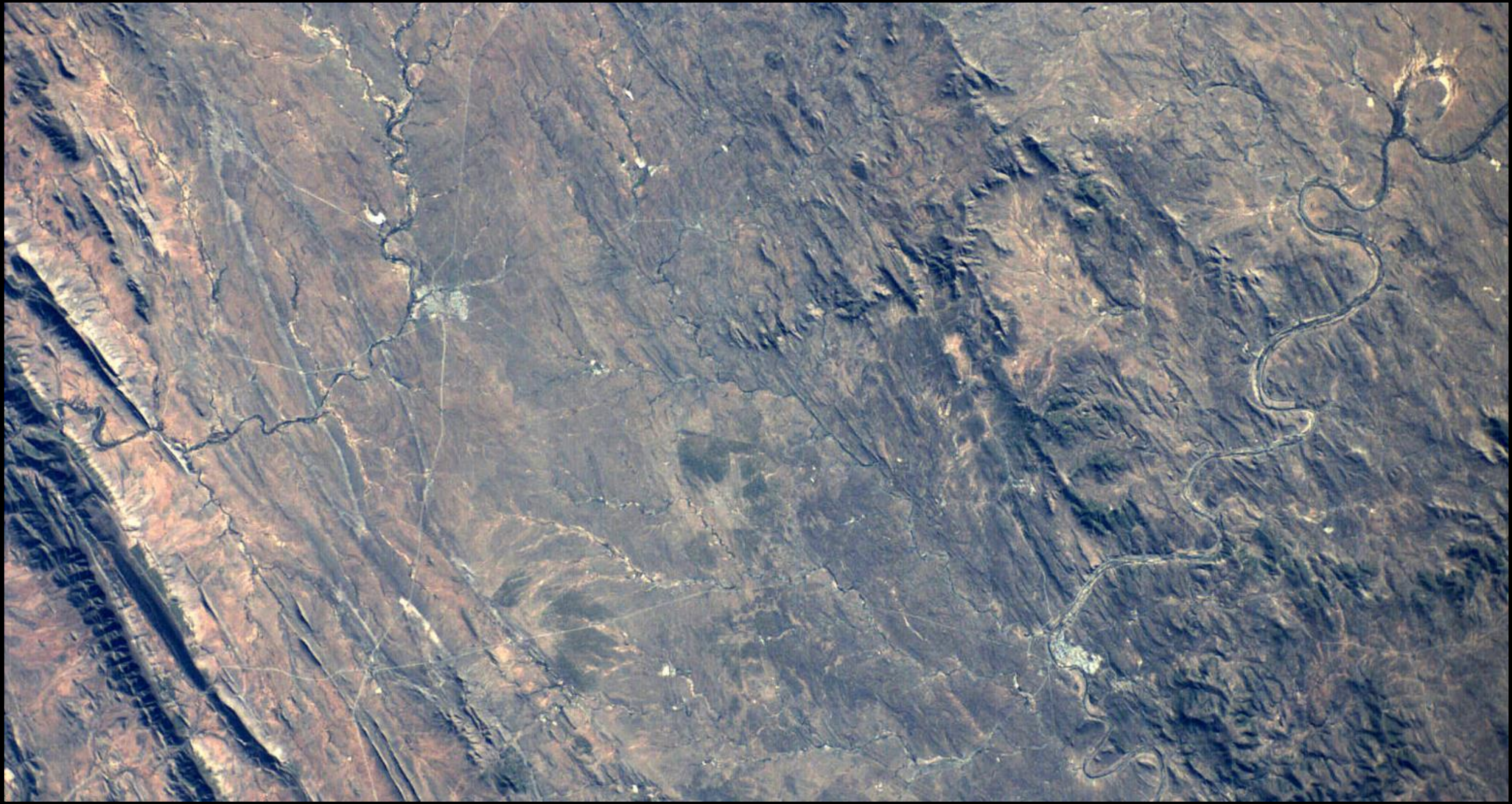
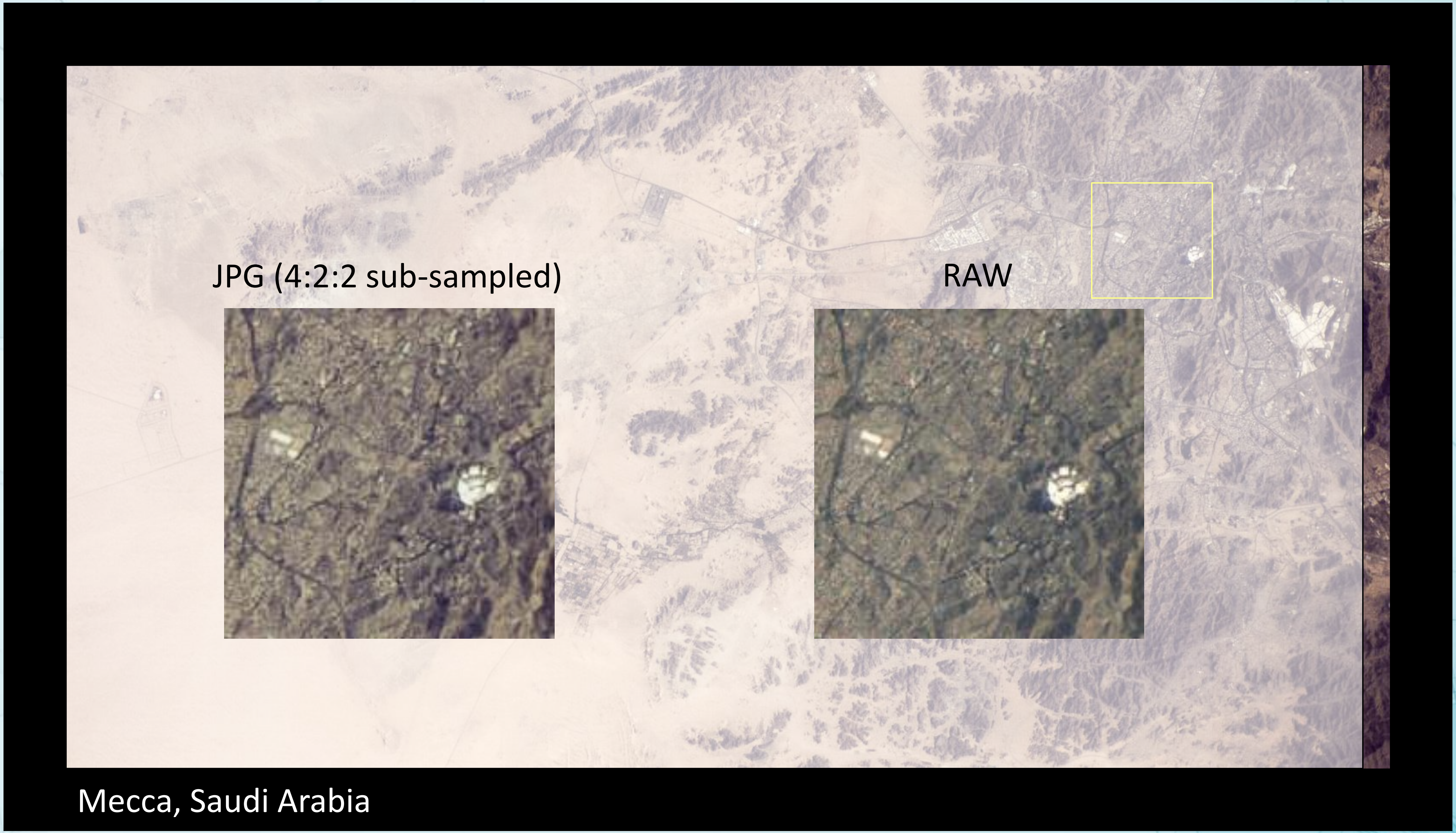


Eastern Cape, South Africa

nSight-1 Images

East London, South Africa

JPG vs RAW



Conclusions

- Components for complete amateur band ground station readily available on the market
- Suitable commercial frequency band radios more difficult to source
- Assembly relatively straight-forward
- Software from various vendors tricky to integrate
- Much experience to be gained in ironing out reliability issues