



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

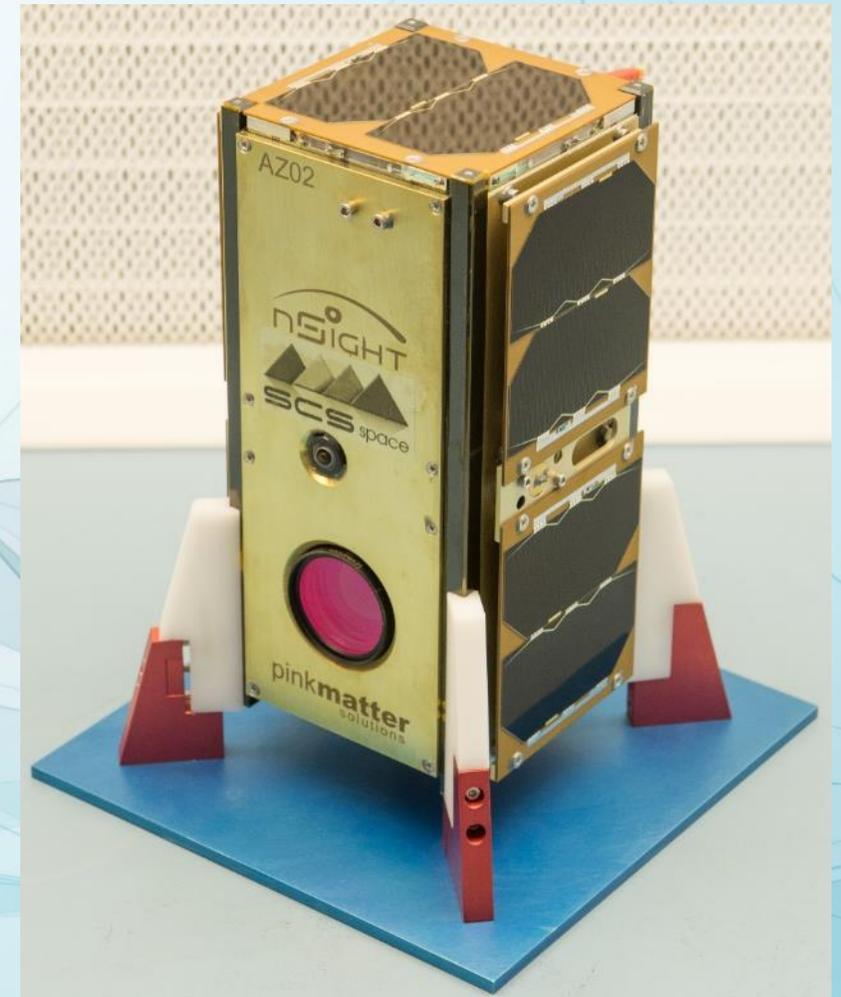
**Presented by:** Francois Visser

**Date:** 13 December 2017

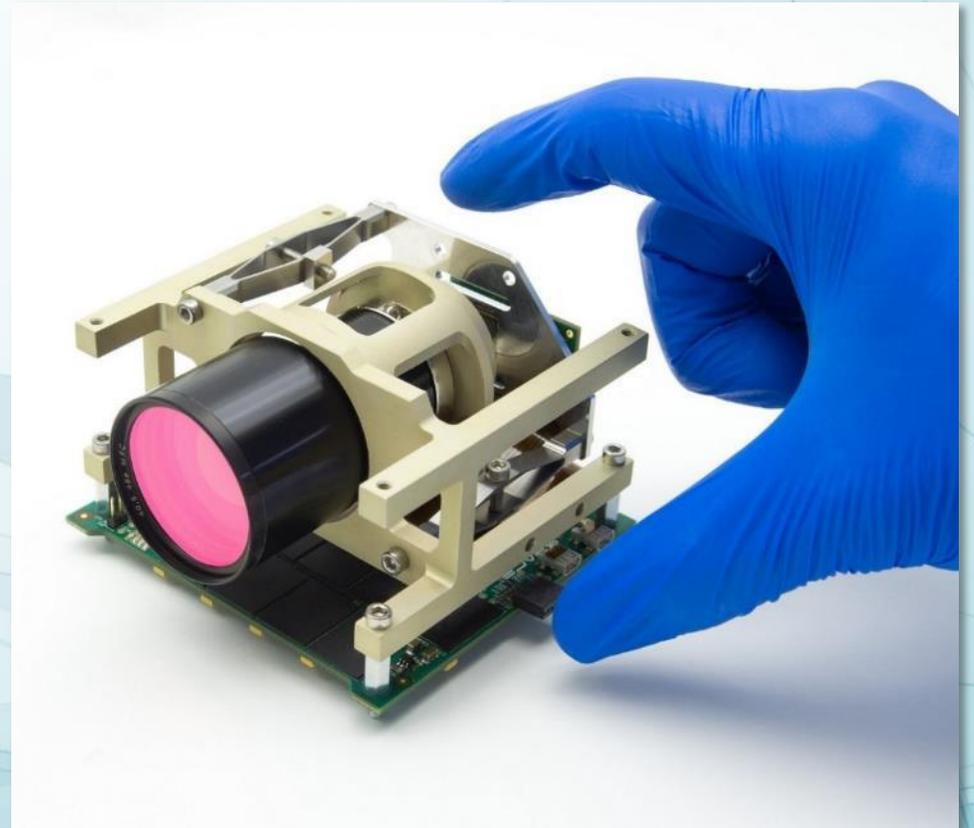
- Dr Lourens Visagie – University of Stellenbosch
- Hendrik Burger – SCS Space

- 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

- 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

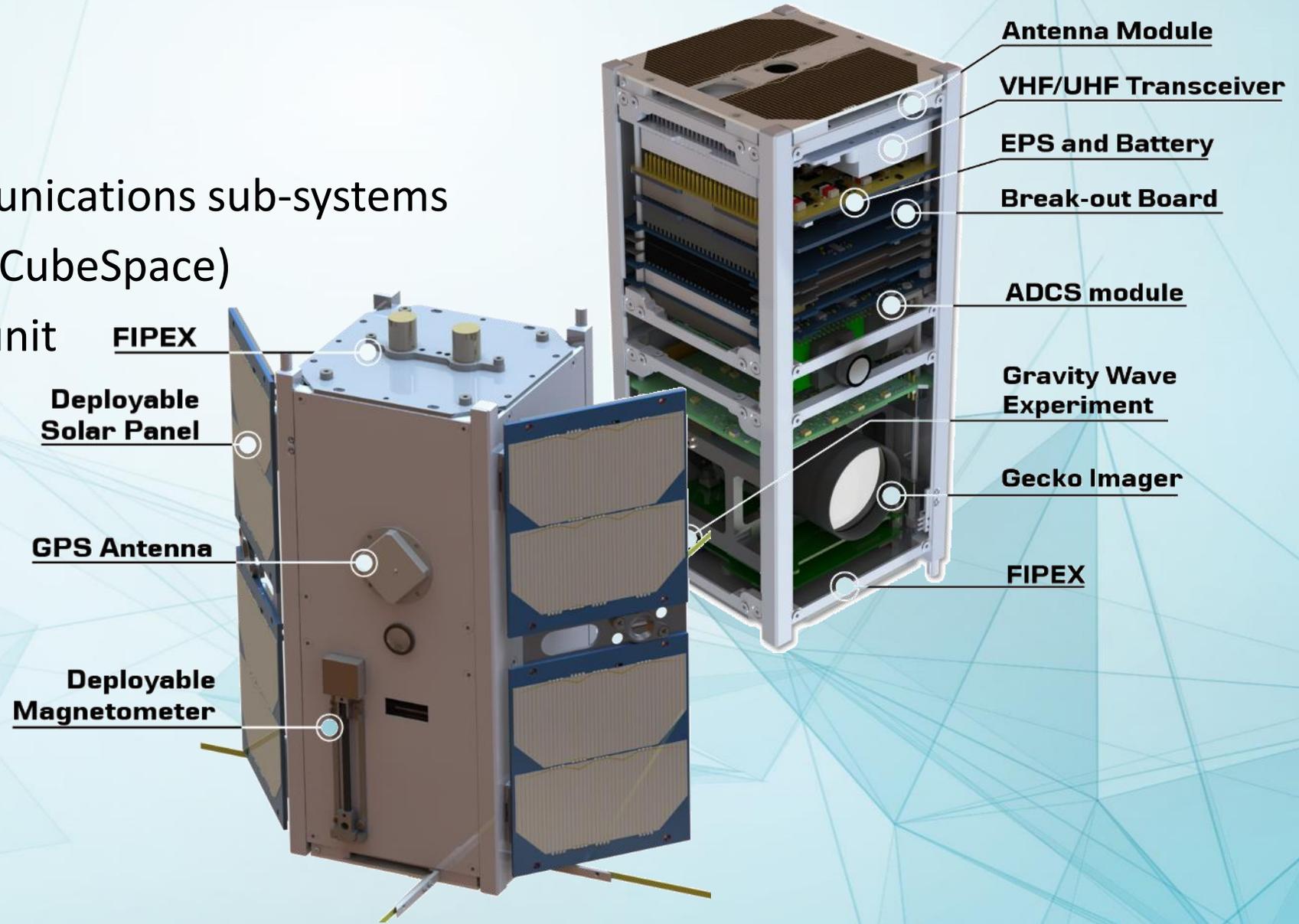


- Testbed for in-house developed “Gecko” Earth imager
- Very short development schedule
- COTS sub-systems used where possible
- Borrowed from partners – CubeSpace, Stellenbosch University, Spaceteq

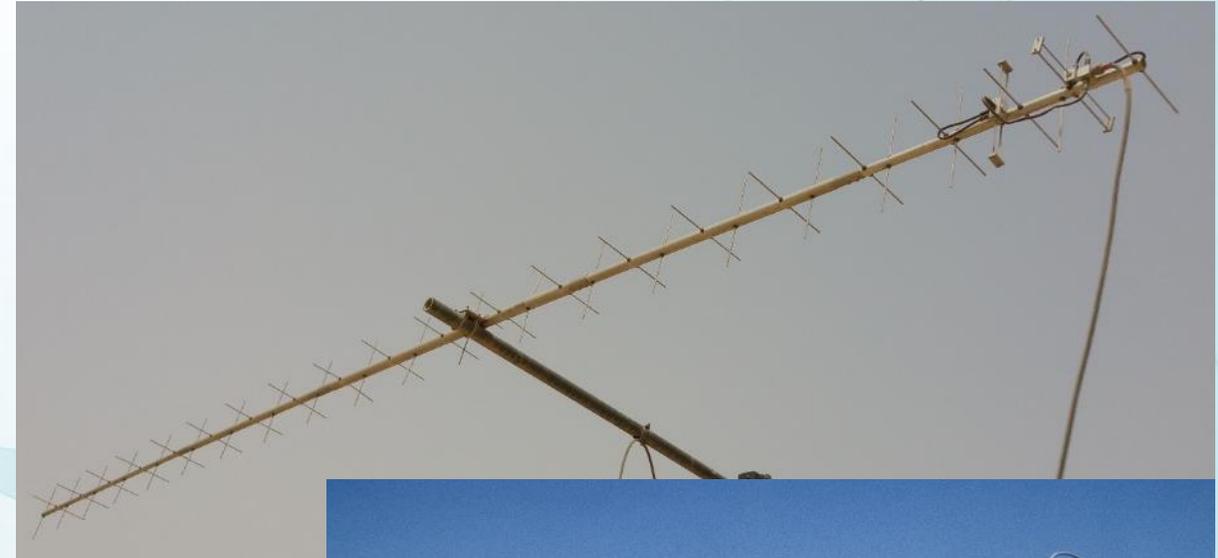


# nSight-1 Mission Overview

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



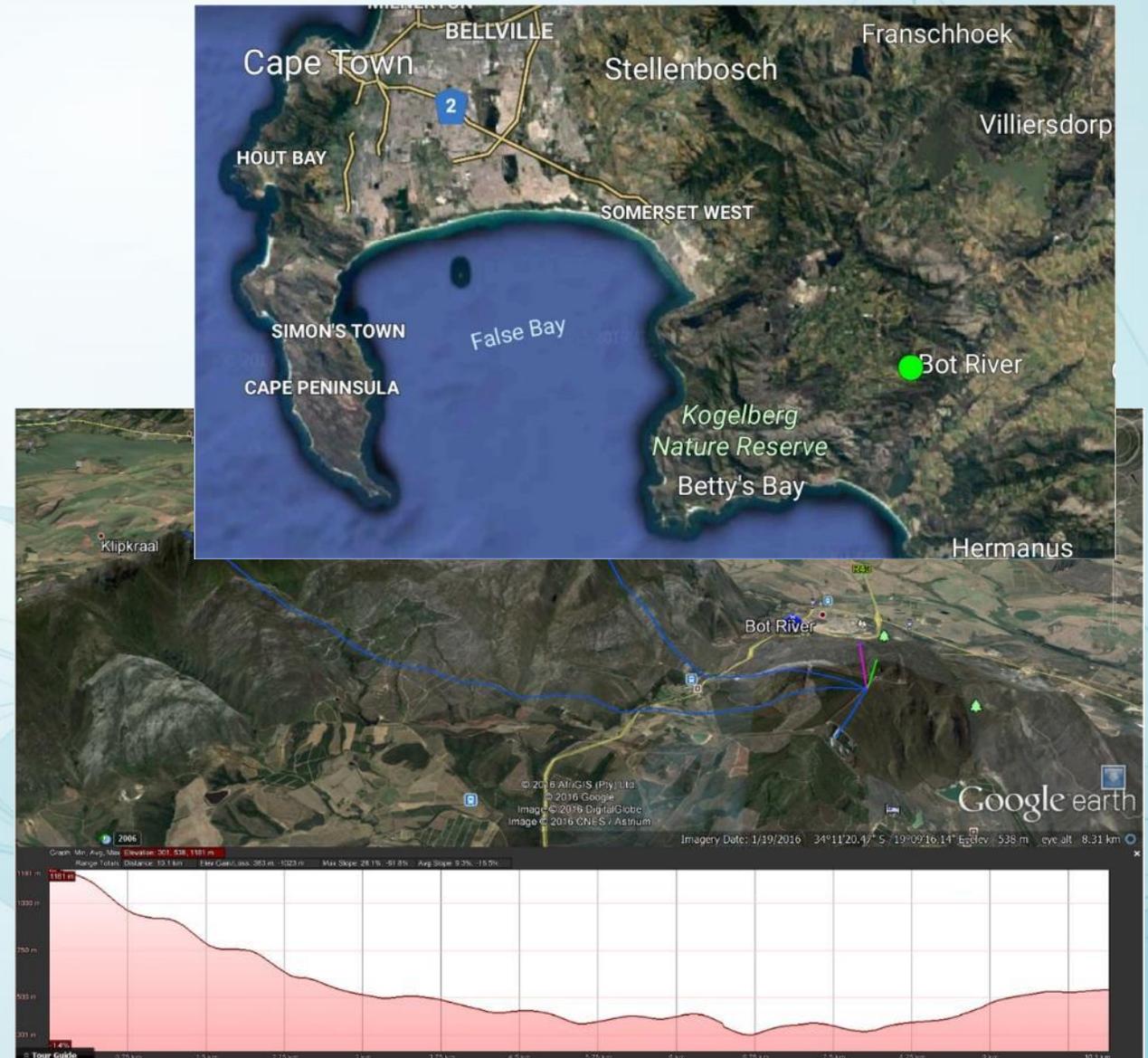
- Link budget
  - Determine performance parameters of the ground station
- Typical Cubesat ground station requirements
  - Antenna type
    - Yagi antennas for VHF and UHF bands are typical
    - Helical antennas are also used
    - For S-band and higher bands, parabolic antennas are typically used



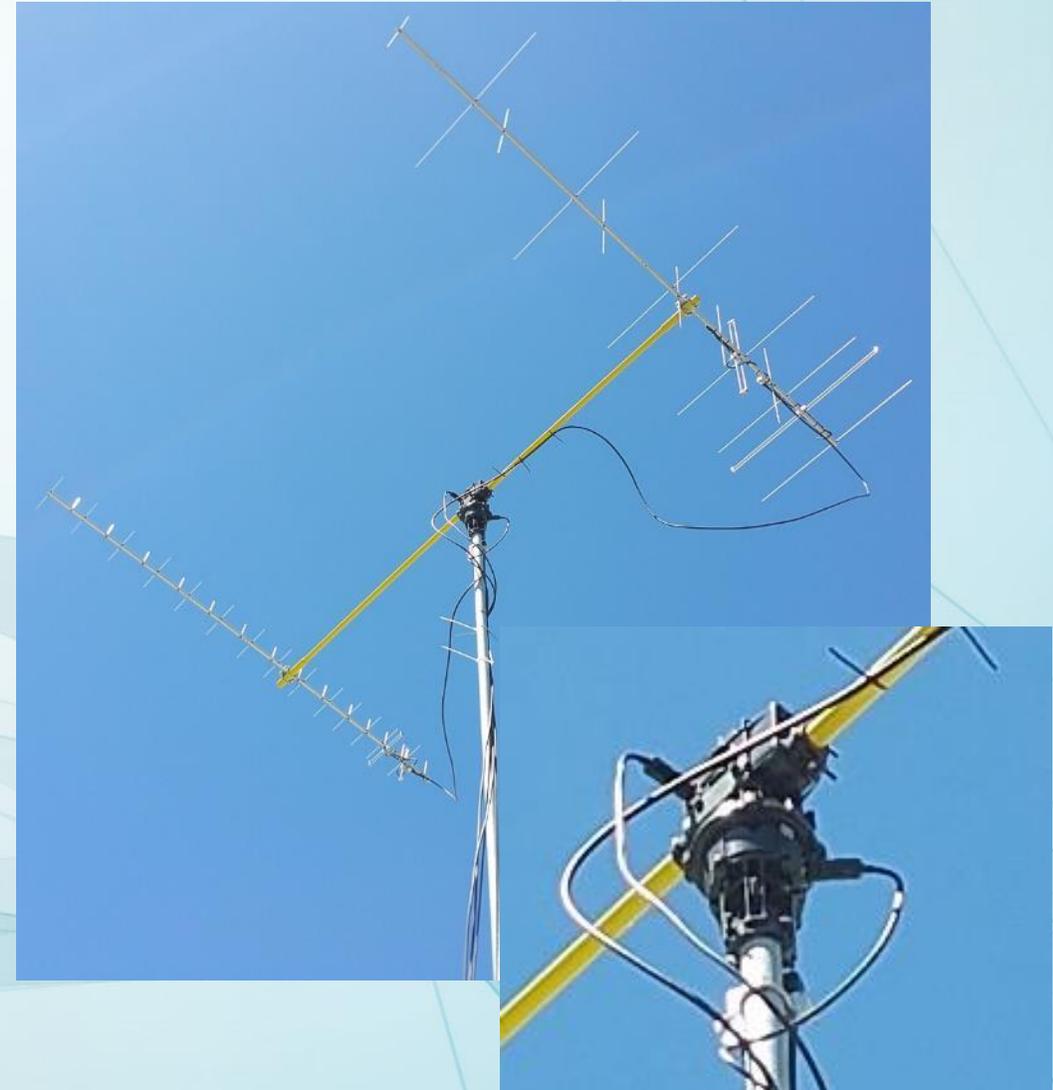
- Antenna gain
  - Circular polarisation advisable
  - Typical gain at VHF is 12 dBic, and at UHF 16 dBic
- Antenna size
  - Antennas can be 3 to 6 m long.
- Antenna pointing
  - Rotator must be selected to carry the weight and angular momentum
- Environmental factors
  - Wind loading, dust, temperature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



- 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



- 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



- 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

- Radio transceiver

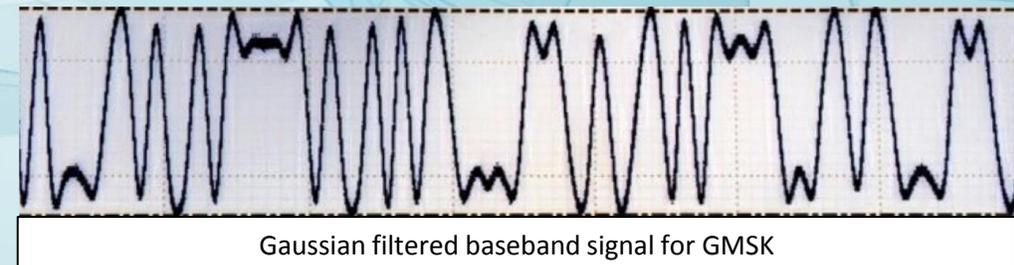
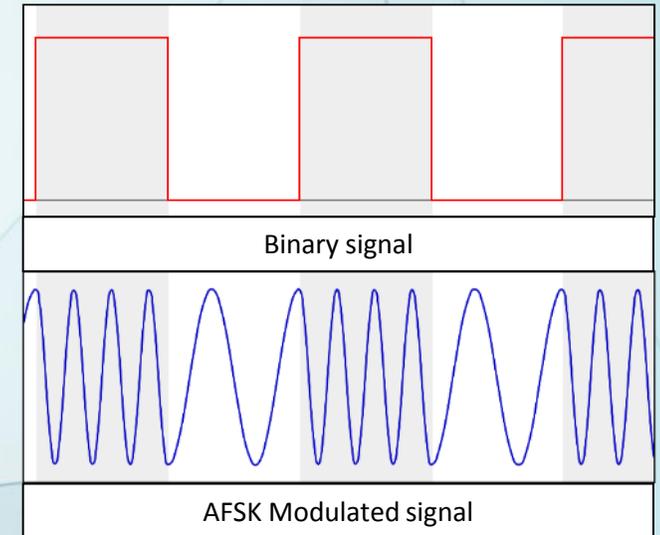
- Transceiver must support the frequencies of operation
- Doppler shift of signals due to relative motion of satellite.
  - Max  $\pm 3$  kHz at 145 MHz,  $\pm 10$  kHz at 436 MHz
- Frequency step size  $< 1$  kHz to allow for Doppler compensation
- Usually control radio functions through PC serial port
- 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



- 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



- 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.



- 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

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

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

- 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

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

- 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

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

**Remote file list**

File Type	Counter	Size	Check-sum
TimLog	1	16060	48EE
TimLog	2	16060	4782
TimLog	3	1409164	6507
Payload2	0	16060	48EE
TimLog	13	4782	
Payload4	1	5124	6FA3
Payload2	10	16060	489D
Payload1	1	2228224	2C2E
Payload2	2	32332	C5F3
Payload2	3	16060	CB4F
Payload2	4	16060	85BE
Payload2	5	16060	81E2
Payload2	6	16060	FB5E
Payload2	7	16060	E57C
Payload2	8	16060	41E8
Payload2	9	16060	ABBA
Payload2	11	16060	9D88
TimLog	9	3826	BBEA
TimLog	5	3826	CA07
TimLog	10	11410	3B7C
TimLog	11	124	7935
TimLog	12	2511544	20B4
TimLog	14	3790	CA45
Payload1	7	2228224	C3AF
Payload1	8	6684672	AC7D
Payload1	9	69632	CD65

**Files selected for download, and current progress**

file Type	Counter	Destination File Name	Downloaded	Total size
TimLog	1	C:\nsight_log_files\Payload1_18_20170929_094948.BIN	16384	2228224
Payload4	15	C:\nsight_log_files\Payload1_18_20170929_094948.BIN	20480	2228224
Payload1	18	C:\nsight_log_files\Payload1_18_20170929_094948.BIN	61440	2228224
Payload1	35	C:\nsight_log_files\Payload1_18_20170929_094948.BIN	0	2228224
Payload1	36	C:\nsight_log_files\Payload1_18_20170929_094948.BIN	0	2228224
Payload1	37	C:\nsight_log_files\Payload1_18_20170929_094948.BIN	0	2228224
Payload1	38	C:\nsight_log_files\Payload1_18_20170929_094948.BIN	0	2228224
Payload1	39	C:\nsight_log_files\Payload1_18_20170929_094948.BIN	0	2228224
Payload1	24	C:\nsight_log_files\Payload1_18_20170929_094948.BIN	2228224	2228224
Payload1	21	C:\nsight_log_files\Payload1_18_20170929_094948.BIN	2228224	2228224
Payload2	9	C:\nsight_log_files\Payload2_18_20170929_094948.BIN	16060	16060

**Comms Log**

```

>> 11:24:16.100 01 02 77 01 02 14 00
>> 11:24:32.726 01 02 78 01 02 FF FF
>> 11:24:37.758 01 02 78 01 02 FF FF
  
```

**Pass table**

Satellite	Start (UTC)	End (UTC)	Duration	Max elev (deg)	Visible
1 nSight	2017-12-05 10:54:44	2017-12-05 10:55:59	00:01:15	2.1718297598130	True
2 nSight	2017-12-06 00:13:50	2017-12-06 00:22:24	00:08:34	21.164076391957	False
3 nSight	2017-12-06 01:49:44	2017-12-06 01:58:42	00:08:58	26.853818579611	False
4 nSight	2017-12-06 03:28:40	2017-12-06 03:33:59	00:05:19	5.5369485461675	True
5 nSight	2017-12-06 05:08:06	2017-12-06 05:10:18	00:02:12	2.512622381287	True
6 nSight	2017-12-06 06:43:30	2017-12-06 05:50:18	00:06:48	8.885823547086	True
7 nSight	2017-12-06 08:18:58	2017-12-06 08:28:25	00:09:27	56.942632027397	True
8 nSight	2017-12-06 09:56:04	2017-12-06 10:02:58	00:06:54	9.6391153429943	True

**Comms Log**

```

2017-12-05 11:20:52 : Block download successful. Downloaded 16384 bytes.
2017-12-05 11:20:52 : Downloading from Payload1.18 - 0 / 2228224 (C:\nsight_log_files\Payload1_18_20170929_094948.BIN)
2017-12-05 11:21:46 : Block download successful. Downloaded 20480 bytes.
2017-12-05 11:21:46 : Downloading from Payload1.18 - 20480 / 2228224 (C:\nsight_log_files\Payload1_18_20170929_094948.BIN)
2017-12-05 11:22:40 : Block download successful. Downloaded 20480 bytes.
2017-12-05 11:22:40 : Downloading from Payload1.18 - 40960 / 2228224 (C:\nsight_log_files\Payload1_18_20170929_094948.BIN)
2017-12-05 11:23:49 : Block download successful. Downloaded 20480 bytes.
2017-12-05 11:23:49 : Downloading from Payload1.18 - 61440 / 2228224 (C:\nsight_log_files\Payload1_18_20170929_094948.BIN)
2017-12-05 11:24:47 : Exception during pass automation : Timeout waiting for TC response. See exception log for details
  
```

**Orbit**

Local time: Tuesday, Tuesday, 05 December 2017, 11:44:00 UTC: Tuesday, 05 December 2017, 09:44:00

**Pass table**

Satellite	Start (UTC)	End (UTC)	Duration	Max elev (deg)	Visible
1 nSight	2017-12-05 10:54:44	2017-12-05 10:55:59	00:01:15	2.1718297598130	True
2 nSight	2017-12-06 00:13:50	2017-12-06 00:22:24	00:08:34	21.164076391957	False
3 nSight	2017-12-06 01:49:44	2017-12-06 01:58:42	00:08:58	26.853818579611	False
4 nSight	2017-12-06 03:28:40	2017-12-06 03:33:59	00:05:19	5.5369485461675	True
5 nSight	2017-12-06 05:08:06	2017-12-06 05:10:18	00:02:12	2.512622381287	True
6 nSight	2017-12-06 06:43:30	2017-12-06 05:50:18	00:06:48	8.885823547086	True
7 nSight	2017-12-06 08:18:58	2017-12-06 08:28:25	00:09:27	56.942632027397	True
8 nSight	2017-12-06 09:56:04	2017-12-06 10:02:58	00:06:54	9.6391153429943	True

**Comms Log**

```

AOS in 01:09:48 (2.4° @ HWS)
2017-12-05 09:44:00 UTC
  
```

- 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

The screenshot displays the 'Simple Tracker' application window. The interface is divided into several sections:

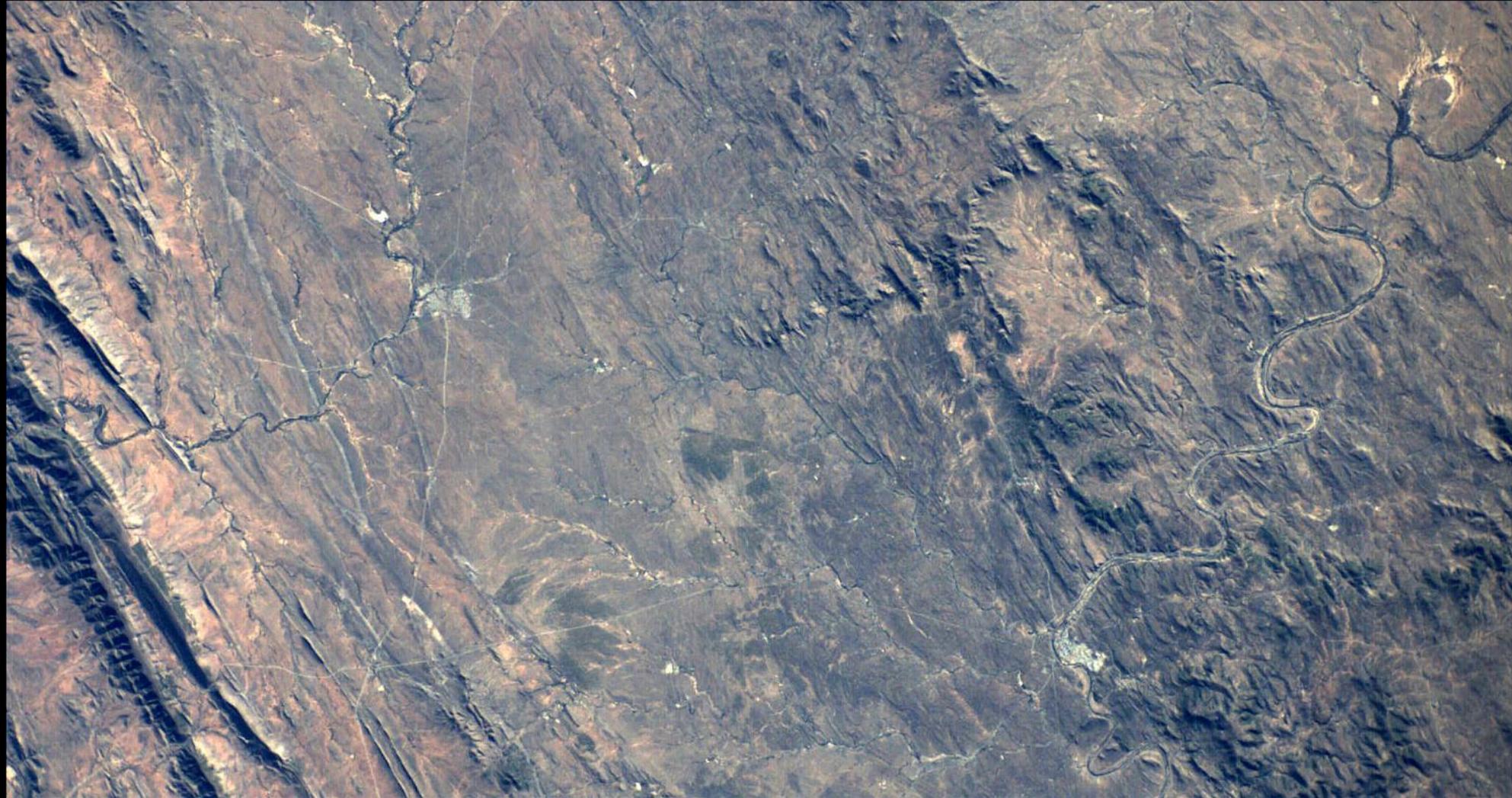
- Satellite tracking:** Shows data for satellite 42726 @ HWS, including Time (2017-11-13 08:56:43 UTC), Azimuth (80.6 deg), Elevation (8.9 deg), Range (1518 km), Range rate (3.1 km/s), and State (Above horizon, illuminated).
- Satellite selection:** Includes fields for NORAD number (42726), Orbit parameters (Load from file...), Use database (checked), Lock, and Start tracking buttons. It also features Time simulation controls for Start time (2017-11-12 14:03:35 UTC), Set to AOS..., Multiplier (1.0), Simulate time, and Stop motion buttons.
- Radio (Icom IC-9100):** Displays radio controller settings, including Reverse doppler (unchecked) and Synchronise time (unchecked). It shows Downlink (Band: UHF receive, Frequency: 435.9000 MHz) and Uplink (Band: VHF transmit, Frequency: 145.9625 MHz, Power: 20.0 W) parameters.
- Antenna (Rotator):** Shows antenna controller settings, including State (Tracking), Azimuth (78.00 deg), and Elevation (10.00 deg).
- Antenna selection:** Includes an Antenna controller dropdown set to 'Rotator' and buttons for Stop, Calibrate, and Park.
- Visualizations:** A graph on the left shows the satellite's elevation angle over time, with a red circle indicating the current position. A graph on the right shows the RSSI history, with a green bar chart representing signal strength over time.
- Ground events:** A log at the bottom shows system messages, including error and warning messages related to the rotator state and hardware reading errors.
- Status bar:** At the bottom, it shows 'State: Ready for overpass', 'LOS in 01:13 (8.9° @ HWS)', and the current time '2017-11-13 08:56:43 UTC'.

- 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

- 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



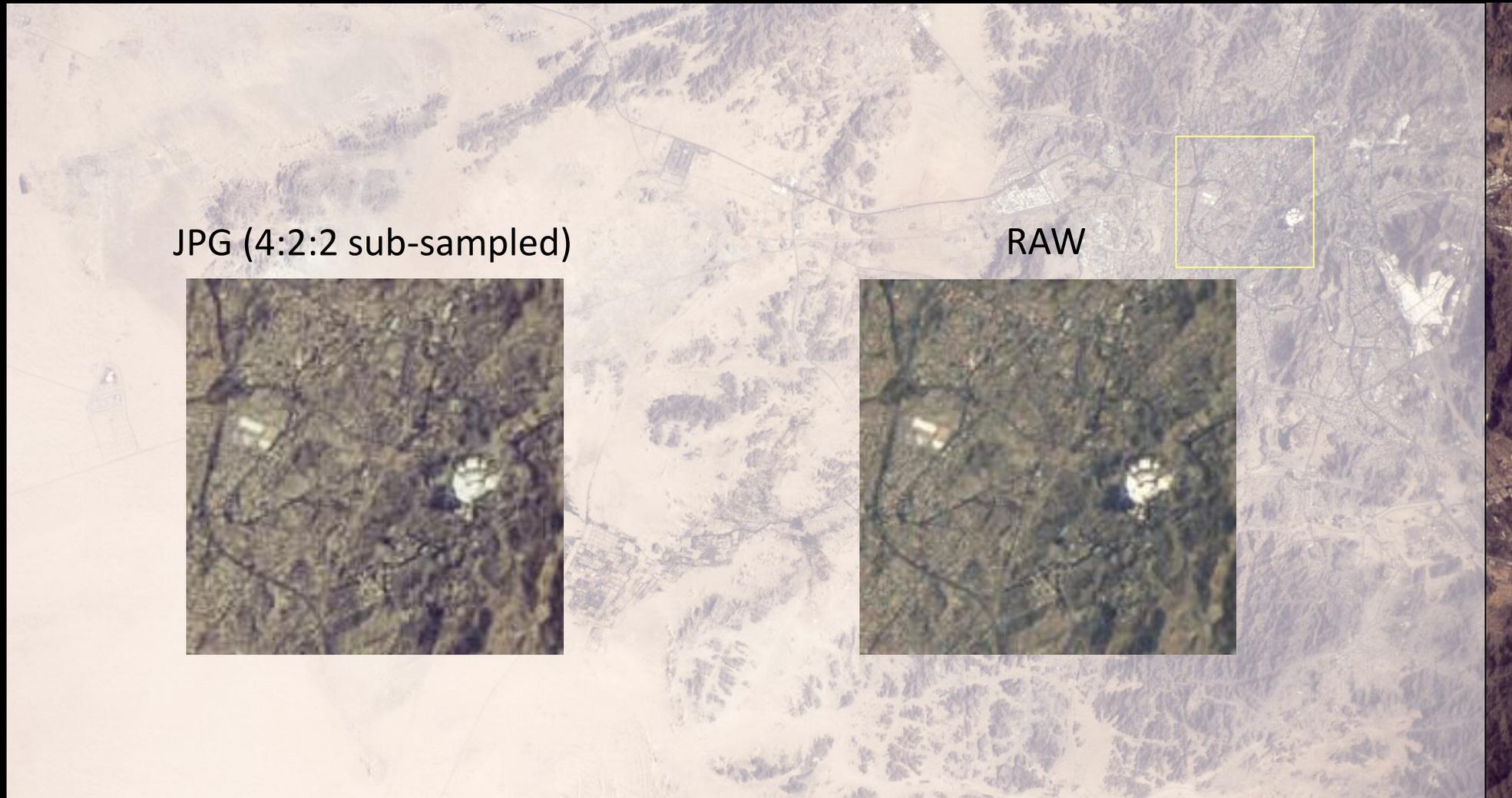
California, USA



Eastern Cape, South Africa



East London, South Africa



JPG (4:2:2 sub-sampled)

RAW

Mecca, Saudi Arabia

- 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