A Technical Background of the ZACUBE-i Satellite Mission Series

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Agenda

• Roadmap
  ▫ In situ monitoring
  ▫ Remote sensing
  ▫ Space weather
• Enabling Infrastructure
  ▫ Ground station
  ▫ AIT
  ▫ Mission assurance
• CubeSat missions
  ▫ ZACUBE-1
  ▫ ZACUBE-2
• Enabling technologies
  ▫ Comms
  ▫ ADCS
  ▫ Propulsion
  ▫ Radiation testing and hardening techniques
ZACUBE-i Roadmap

- **Development Dimension**
  - **Research and Development**
    - Academic, Research, Subsystems Prototyping
  - **Missions**
    - ZACUBE-2 (3U)
    - ZACUBE-1 (1U)
    - ZA-Aerosat (with Stellenbosch University) (2U)
  - **Future Missions**
    - In Situ Monitoring Mission Series 1U:
      - Theme: Remote Data Collection
    - Space Weather Mission Series 1U / 3U:
      - Theme: South Atlantic Magnetic Anomaly
    - 3U / 6U Earth Observation mission series:
      - Theme: complementary to EOSat
  - **Launches**
Nano-Satellite Constellations for Monitoring Climate Change Impact on Africa

Multi-Spectral Remote Sensing

Monitoring temperature, CO2 levels, precipitation and ocean levels is important as it indicates a change in the Earth's climate.

- UV
- Visible
- NIR
- SWIR
- MWIR
- LWIR

Wavelength of interest

National resource management
- vegetation monitoring
- wildlife/livestock tracking
- deforestation
- urbanisation

Thermal monitoring
- industrial condition monitoring
- fire detection

Atmospheric parameters
- monitor CO2
- greenhouse effects
- water vapour

Africa is one of the world's fastest developing continents. This impacts the climate through increased carbon dioxide emissions, deforestation and pollution. Monitoring climate change and its impact on the environment can help manage these challenges while keeping Africa's carbon footprint to a minimum.

In-situ sensor network connectivity

- Earth-based sensor nodes distributed throughout Africa
- sensor networks provide information about the environment
- remote monitoring of desert, ocean, and forest regions
- sensor data is captured with nano-satellite constellations allowing for remote placement of sensor nodes
- remote sensing is possible without the need for existing terrestrial connectivity

Challenges

- agricultural and land management
- human and economic development
- disaster monitoring (flooding, fire)
- natural resource management
- climate change monitoring
- environmental protection
- food security

What is different to existing solutions?

- comparatively low cost solution
- high temporal resolution (≈ 1 hour revisit time)
- medium spatial resolution (≈ 25m)
- developed in Africa as a technology driver
- distributed ground support (continent wide)

Sensor Node

- monitor atmospheric and environmental conditions
- transmit sensor data to nano-satellite constellations

Space Segment

- LEO constellations with 9 satellites (3 per orbital plane)
- Multi-Spectral Remote Sensing:
  - space-based multi-spectral image capture (25m ground sampling distance, 1 hour revisit time)

Ground Segment

- Inter-connected ground station network
- receive information from nano-satellite constellations

In-situ sensor network

- information is collected from Earth-based sensor nodes and relayed to geographically distributed ground stations
ZACUBE-i Space Weather Experiment Objectives

- **Ultimate goal**: characterise beam pattern of SuperDARN array at SANAE IV in Antarctica.
  - Field of view: ~South
  - Azimuth range: 30°
  - Elevation range: 0 to 30°
  - 16 selectable fan beams
- **Incoming wave from satellite refracts through ionosphere**, angle not known, can’t be used directly to measure beam pattern.
ZACUBE-i Space Weather Experiment Objectives

- Measurements first done in Hermanus where existing equipment (ionosondes, GPS tomographers) can accurately calibrate model of ionosphere.
- Construct interferometer to measure incoming beam angle.
- Correlate with ray traced analysis of beam path using calibrated ionospheric models.
- Verify interferometer performance.
ZACUBE-i Space Weather Experiment Objectives

- Interferometer then moved to SANAE where ionospheric model is not that well known, measurements repeated.
- Difference between true and apparent elevation angles = refraction angle, proportional to total electron content (TEC) along ray path.
- Acquired TEC data augment existing polar ionosphere data.
- Knowledge gained of top side ionosphere.

SuperDARN array at SANAE-IV, Antarctica
Things to watch out for

- Analysis shows that apparent elevation angle remains constant for a large range of actual elevation angles.
- As long as this constant $e_a$ is within 30 deg range of radar array’s beam, it should be useful to characterise the beam pattern as it depends on azimuth variation during satellite’s overpass.
- Lowest useful frequency must be lower than 14.099 MHz for all incident angles and variable states of the ionosphere, otherwise the signal will not penetrate from the satellite to the ground station.
ZACUBE-i Space Weather Experiments

Main array

Interferometer array
Components of interferometer array

HF Direction Finder Array
Constructed at SANSA, Hermanus

7 crossed loop antenna modules with preamp for each loop element

HF downconverter bank
19" rack module

14 MHz RF & 12 VDC over coax

SA612 downconverter IC
Input: 200 to 300 mVp-p, = 20 kHz

16 way power splitter network

1 kHz baseband signals

14.096 MHz
Local Oscillator
5 dBm, 50 Ω output

To PC capture interface
Infrastructure: Ground station

- Typical amateur satellite tracking installation
- VHF / UHF Amateur bands
- Next phase: 2.4 m dish for S-band, C-band dish
Infrastructure: AIT

- Flight model integration and testing facilities
- Clean room
- New Electrical Engineering building
  - 2000 ft² satellite development and production facilities
  - 8000 ft² training labs and classrooms
Infrastructure: Mission Assurance

• Access to other facilities in the region
  ▫ Hot vacuum and bakeout
    • iThemba Labs
  ▫ Vibration testing
    • Tellumat
  ▫ EMC testing
    • Anechoic chamber, Houwteq

• To be acquired
  ▫ Thermal chamber
  ▫ Thermal vacuum chamber

• Hardware-in-the-loop testing
  ▫ To be established by newly appointed research chair as a national facility
ZACUBE-1 mission objectives

- **Space weather mission**
  - Initiate HF ionospheric propagation studies of ZACUBE-i series
  - SuperDARN characterisation

- **Skills development**
  - Postgraduate students
  - Establish infrastructure
  - Professional development
  - Building legacy

- **Technology demonstrator**
  - Deployable HF antenna
  - UHF/VHF transceiver

- **Camera**
  - Awareness

- **Research output**
  - Conferences, journals, patents
Time line

- ZACUBE-1
  - 2011/12
  - 30 000 man/hrs
ZACUBE-1 layout

- Deployable magnetometer
- ISIS deployable VHF/UHF antenna
- Deployable HF antenna, beacon transmitter electronics and VGA camera
- Magnetic ADCS with torquer coils
- Clyde Electronic Power Supply (EPS)
- VHF/UHF communications module
- Pumpkin On-Board Computer (OBC)
- Pumpkin structure
ZACUBE-1 HF beacon
ZACUBE-1 Images
ZACUBE-1 Telemetry

ZACUBE-1 Temperature Telemetry - Single Orbit

ZACUBE-1 Internal Magnetometer Telemetry

ZACUBE-1 Battery Bus Voltage - Multiple Orbits
ZACUBE-2

- 3U CubeSat
- S-Band Transmitter
- ADCS System Developed by ESL at Stellenbosch University
- L-Band Receiver
- VHF/UHF Communication System
- HF Beacon Payload
- On-Board Computer (OBC)
- 5 MP Camera Payload
ZACUBE-2

- **ADCS**
  - Unique control method using aerodynamic drag
  - Deployable UHF / L-band antennas also serve as stabilising tail feathers
  - Deployable side panels control roll angle
  - Full redundant backup with magnetorquers and reaction wheels.
  - CubeSense ADCS sensor module

- Space weather sensors to be determined
- Collaboration with other institutions/universities in SA, Europe and America
- Government approved funding for development
QB50 Participation

- **QB50 mission**
  - 50 International CubeSats with science payloads to model the upper layers of the thermosphere
  - Launch January 2016

- **ZA-AeroSat (Africa’s only contribution to QB50)**
  - SU project to design and manufacture 2U CubeSat
  - F’SATI supplies comms payload – TT&C transceiver (CMC) and deployable antenna system
  - Demonstrate passive aerodynamic stabilisation (antennae used like plumes on a shuttlecock)
  - Fipex science sensor and new CubeStar star tracker
Enabling Technology: Communications

- S-band shorted annular ring patch antenna
- 7 dBi gain
- Circularly polarised
- Light weight: <20 g without screws
- 89 x 83 x 4.3 mm
Enabling Technology: Communications

- **S-band transmitter for large amounts of payload data**
  - 2 Mbps / 1 W RF transmit power
  - QPSK modulation
  - CCSDS compliant FEC
  - Future improvements
    - 50 Mbps downlink
    - SDR
    - Transceiver: 10 Mbps uplink

- **UHF / VHF transceiver for telecommand / telemetry**
  - 1.2 kbps AFSK or 9.6 kbps GMSK amateur radio transceiver
Enabling Technology

- Nanosatellite propulsion, debris mitigation
  - Wits University
- ADCS
  - ESL, Stellenbosch University
- Radiation testing and hardening
  - iThemba Labs
  - University of Pretoria
- Advanced manufacturing and nano-tech
  - NLC, ALC
Future nano-sat missions

- Nano-satellite constellations provides a paradigm shift from existing platforms:
  - High temporal resolution / medium ground sampling resolution
    - 30 min / 20 m vs. 8 hours / 10 m
  - Shift in applications
  - Technology threshold low
  - Can be done by Africa, for Africa, in collaboration with our international partners
Thank you