Vicarious Calibration Site Selection
Spaceborne imaging spectroscopy EO missions* - Overview

Legend

- Running missions
- Terminated missions
- Future missions

* The multispectral Sentinel-2 mission (ESA) is listed for comparison

Complete list on www.enmap.org
Running and terminated spaceborne imaging spectroscopy EO missions – Launch and life time

- Hyperion / EO-1
- CHRIS / PROBA
- HJ-1A
- FY-3A/ MERSI
- HySI/ IMS-1
- TG-1
- Resurs-P No.1
- Resurs-P No.2
- CMODIS
- HICO

NASA, USA
ESA & UK
CASC, China
CMA, China
ISRO, India
CAS/SITP, China
Roscosmos, Russia
Roscosmos, Russia
CAS, China
NRL, USA
Spaceborne imaging spectroscopy running and terminated missions – Spectral characteristics

Legend:
- - - - VNIR
- - - - SWIR
- - - - TIR
- - - - PAN
Spaceborne imaging spectroscopy running and terminated missions – Spatial characteristics

- **Hyperion/EO-1**
- **CHRIS/PROBA**
- **HJ-1A**
- **FY-3A/ MERSI**
- **HySI/ IMS-1**
- **TG-1**
- **Resurs-P1**
- **Resurs-P2**
- **HICO**
- **CMODIS**
- **Sentinel-2A**

**Swath [km]**

- **300 km**
- **240 km**
- **210 km**
- **180 km**
- **150 km**
- **120 km**
- **90 km**
- **60 km**
- **30 km**

**Pixel size [m]**

- **30 m**
- **60 m**
- **90 m**
- **120 m**
- **150 m**
- **180 m**

- **7.5 km**
- **14 km**
- **50 km**
- **128 km**
- **30 km**
- **38 km**

**Swath and Pixel Size**

- **MODE 1**: 100 m
- **MODE 2**: 250 – 1000 m
- **CMODIS**: 400 - 500 m
- **HICO**: 90 m
- **Hyperion/EO-1**: N/A
- **CHRIS/PROBA**: N/A
- **HJ-1A**: N/A
- **HySI/ IMS-1**: N/A
- **TG-1**: N/A
- **Resurs-P1**: N/A
- **Resurs-P2**: N/A
- **Sentinel-2A**: 10 – 60 m

**Swath [km]**

- **42 – 192 km**

**Pixel Size [m]**

- **18 m**
- **36 m**

**Swath and Pixel Size**

- **MODE 1**: 30 m
- **MODE 5**: 30 m
- **MODE 4**: 30 m
- **MODE 3**: 30 m
- **MODE 2**: 30 m
Future spaceborne imaging spectroscopy EO missions – launch and life time

University of Hawaii, USA
Roscosmos, Russia
DLR, Germany / Teledyne, USA
China Commercial, China
Roscosmos, Russia
ASI, Italy
ISRO, India
Roscosmos, Russia
JPL, USA
Boeing, USA
ISRO, India
DLR, Germany
METI/JAXA, Japan
ASI, Italy/ISA, Israel
ESA, UK
CNES, France
NASA/JPL, USA
China
<table>
<thead>
<tr>
<th>Mission</th>
<th>VNIR</th>
<th>SWIR</th>
<th>TIR</th>
<th>PAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hiakasat</td>
<td>tbd</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resurs P3/4 &amp; 5</td>
<td>tbd</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DESIS</td>
<td>240</td>
<td>132</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TAIS</td>
<td></td>
<td>320–328</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CCRSS</td>
<td>92</td>
<td>157</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRISMA</td>
<td>150</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GISAT</td>
<td></td>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>ECOSTRESS</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Boeing</td>
<td>220</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CartoSat-3</td>
<td>50</td>
<td>150</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EnMAP</td>
<td>98</td>
<td>130</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HISUI/ALOS-3</td>
<td>57</td>
<td>128</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shalom</td>
<td>241</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLORIS/FLEX</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HYPIXM-P</td>
<td>210</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HyspIRI</td>
<td>210</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GF5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Legend:
- VNIR
- SWIR
- TIR
- PAN

Spaceborne imaging spectroscopy future missions – Spectral characteristics
<table>
<thead>
<tr>
<th>Mission</th>
<th>Swath [km]</th>
<th>Pixel size [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hiakasat</td>
<td>500 km</td>
<td>N/A</td>
</tr>
<tr>
<td>Resurs P3/4 &amp; 5</td>
<td>360 – 400 km</td>
<td>38 – 69 m</td>
</tr>
<tr>
<td>DESIS</td>
<td>44 - 57 km</td>
<td>30 m</td>
</tr>
<tr>
<td>TAIS</td>
<td>30 km</td>
<td>28 - 30 m</td>
</tr>
<tr>
<td>CCRSS</td>
<td>10 km</td>
<td>2.5 – 5 m (PAN)</td>
</tr>
<tr>
<td>PRISMA</td>
<td>16 km</td>
<td>2 m (PAN)</td>
</tr>
<tr>
<td>GISAT</td>
<td>105 – 150 km</td>
<td>10 m (VNIR/SWIR)</td>
</tr>
<tr>
<td>ECOStress</td>
<td>150 km (VSWIR)</td>
<td>100 m (TIR)</td>
</tr>
<tr>
<td>HySpecIq</td>
<td>600 m (TIR)</td>
<td>30 – 60 m (VSWIR)</td>
</tr>
<tr>
<td>CartoSat-3</td>
<td>600 m (TIR)</td>
<td>N/A</td>
</tr>
<tr>
<td>EnMAP</td>
<td>30 km</td>
<td>30 m</td>
</tr>
<tr>
<td>HISUI/ALOS-3</td>
<td>16 km</td>
<td>2 m (PAN)</td>
</tr>
<tr>
<td>Shalom</td>
<td>600 m (TIR)</td>
<td>30 m</td>
</tr>
<tr>
<td>FLORIS/FLEX</td>
<td>30 km</td>
<td>30 m</td>
</tr>
<tr>
<td>HYPIXM-P</td>
<td>30 km</td>
<td>30 m</td>
</tr>
<tr>
<td>HypIIRI</td>
<td>30 km</td>
<td>30 m</td>
</tr>
<tr>
<td>GF5</td>
<td>30 km</td>
<td>30 m</td>
</tr>
</tbody>
</table>

Spaceborne imaging spectroscopy future missions – Spatial characteristics
Why Focus On Calibration And Validation?

- Calibration and validation is an important underpinning need for imaging spectroscopy mission especially post-launch to track sensor performance, and, throughout the life of the mission;

- Some sensors may have little or no on-board calibration;

- Calibration and validation is a generic requirement shared amongst all sensor providers where GSIS could make fruitful contributions to enable collaborative efforts;

- The need for multi-temporal work and wall-to-wall coverage is inevitable
  - This cannot be done with a single sensor in the foreseeable future: multi-sensor “fusion” is inevitable. Calibration, cross-calibration is the lynch pin to enable this;
Hypothetical Virtual Constellation Of Spaceborne Imaging Sensor with 5 Hypothetical Sensors

Video courtesy Andreas Mueller, DLR
Seamless Global Precipitation Measurement From 12 Different Sensors

Video courtesy NASA’s Scientific Visualization Studio
More information: svs.gsfc.nasa.gov/goto?4283
Why Australia?

- in southern hemisphere => advantageous for calibration during the northern hemisphere winter;
- 70% arid areas => dry, low rainfall, low vegetation, low probability of clouds, clear skies;
- Large areas away from influences of populated areas;
- Very flat country;
- Very high earth observation usage, no satellite, way of giving back;
Aim

To build a vicarious calibration site specifically for imaging spectroscopy missions underpinned by instrumentations at least meeting (and aiming for beyond) those of current CEOS WGCV endorsed vicarious calibration sites.
Kalgoorlie – surface mineral mapping regolith cover

kaolin disorder

- Cudahy et al. MERIWA (2005)

Depositional

Erosional
Example: Mineralogical keys/clues for transported material:
Lack of primary minerals + Poorly-ordered kaolin + Hematite-rich

References:
Cudahy (1992)
Kanowna: Kaolin Disorder

Geoscience and Remote Sensing Society

Poorly ordered

Well ordered

500 m
Kanowna: Hematite-Goethite ratio

Geoscience and Remote Sensing Society

Diagram showing the hematite to goethite ratio at 880 nm to 920 nm wavelengths. The diagram includes layers such as saprolite, saprock, fresh rock, mottled zone, pisolithic duricrust, and an increasing iron oxide/gibbsite layer with decreasing Al-substitution in iron oxide, leading to hematite and goethite.
Recommended Vicarious Calibration Site Characteristics (after Scott, et. al 1996)

**Physical Characteristics**

1. A high-reflectance results in higher signal-to-noise ratio (SNR) which, in return, increases overall accuracy.
2. The higher the spatial uniformity of the area, the lesser the effects of generalizing the reflectance data to the size of the full test site.
3. Spectral uniformity of the site eases the calibration procedure.
4. Temporal uniformity of the site eases the calibration procedure.
5. The site should have little or no vegetation that can deteriorate spectral and temporal uniformity.
6. Higher elevation reduces the error due to aerosols.
7. A Lambertian site surface is preferable since it decreases errors caused by different solar and view geometry.
Recommended Vicarious Calibration Site Characteristics (after Scott, et. al 1996)

Environmental Conditions

1. High probability of cloud free days provides more time for calibration studies.
2. A longer distance to densely populated areas and/or industrial facilities decreases the effect of anthropogenic aerosols.
3. A location far from the seas or other large water bodies minimizes the influence of atmospheric water vapor.
4. Having a site in an arid region minimizes probability of precipitation and this in turn may change the surface BRDF. Also, in arid regions, the probability of a cloudy weather is minimum.
5. Having a large site minimizes the unwanted effects of scattering of light from areas outside the target area.
Recommended Vicarious Calibration Site Characteristics (after Scott, et. al 1996)

Location
1. Easy access to the site is an advantage.

Instrumentation
1. Instrumented test sites are preferable.
Systematic Vicarious Site Identification

Problem: How to systematically identify site(s) suitable for calibration of moderate spatial resolution sensors (~30m) across 450-2500nm?

Strategy: Analysis of Landsat archive.
- Operating since 1970’s;
- 30m pixel, 120x120km swath;
- 6 bands covering VNIR SWIR;
- 16 day revisit therefore extensive archive.

Site selection search criteria:
- Spatially >100x100m, at least 3x3 30m pixels, preferably larger;
- High reflectance (VNIR > 30, SWIR > 40) and preferably lambertian;
- Spatial, spectral and temporal uniformity (CofVar < 0.15);
- Consistently bare ground (BG Class > 0.75);
- Low relief to flat (Slope < 2%);
- Favourable climatic conditions.
Method – Project Workflow/Algorithm

NCI Raijin & AGDC

TM 5 2003-2010

Tile 1  Tile 824

Core 1  Core N

40-60 images

“dry” scenes

GDAL mosaic

AGDC API “Stacker” , Python code & scripts

Spectral Indices

*NDVI
*MNDWI etc

PQA

Cover Classification

*Bare ground  *Vegetation
*Surface water  *Low albedo
*Cloud

Temporal stats

*Class occurrence
*Normalised class occurrence
*Observations

“Bare ground” temporal stats

• Band µ & σ
• Coefficient of variation
*VNIR Albedo µ&σ
• SWIR Albedo µ&σ

• Data visualisation
• Integration
• Interrogation

ENVI

*Data visualisation
*Integration
*Interrogation
Image Search criteria

\[(\text{Obs\_tot} > 40) \cap (\text{Norm\_Class\_Occur}[\text{Bare\_ground}] > 0.75) \cap (\text{Alb\_VNIR} > 0.3) \cap (\text{Alb\_SWIR} > 0.4) \cap (\text{CofVar} < 0.15)\]
First Cut

- Green vectors show high rainfall zone >600 mm pa
- Red circles show radius of 400 km (half day’s drive) from major airport
- Image is VNIR-SWIR temporal means
Some insights

- **Salt lakes**
  - Most salt lakes are similar with high spatial homogeneity (overall within 6% for VNIR-SWIR and 9% for VNIR with large patches of within 3% reflectance difference);
  - Temporal variations are higher than coastal and inland sand sites (lakes are mostly <25% difference for VNIR. NB. This is between dates not reflectance);
  - Meets albedo threshold criteria (>30%) for VNIR but signal low for SWIR (water);

- **Coastal sands**
  - Spatial homogeneity not as good as salt lakes (up to 15% reflectance value difference);
  - Temporal variations low (<10%);
  - Meets albedo threshold criteria for all wavelengths;
  - Have to consider issues related to aerosols, spatial extent and topography;

- **Inland sand dunes/deserts**
  - Spatial homogeneity similar to coastal sands (up to 12% reflectance value difference);
  - Temporal variations low similar to coastal sands;
  - Meets albedo threshold criteria for all wavelengths;
  - Have to consider issues related to access/remoteness and topography;
Lake Lefroy

Access

- Location: 31.2662° 121.716°, elevation ~350 m
- 60 km S of Kalgoorlie-Boulder and 550 km E of Perth
- Nearest airport Karlgoorlie ~25,000 people and has major air, rail and road links to capital cities in Australia.
- A bitumen road between Kalgoorlie-Boulder and the township of Kambalda on the northern edge of Lake Lefroy
- Nearest town and accommodation: Kambalda, less then 5 km

Landscape/Landform

- medium-sized playa lake (50 km X 10 km) within Lefroy Palaeodrainage on Yilgarn Craton of Western Australia;
- bed of Lake Lefroy is extremely flat, mean elevation of the lake bed approximately less than 286 m, crust is halite up to 10 cm thick, but often no more than 1-2 cm in thickness. Halite covers approximately 64% of the lake bed, the crust becomes thinner towards the lake shore and lake islands.

Vegetation

- No vegetation on lake bed but surrounding vegetation consists of 50 vascular plant species with the predominant families of species being Chenopodiaceae, Asteraceae, Aizoaceae, Poaceae, Portulacaceae and Frankeniiaceae.
Lake Lefroy

Climate
- rainfall @ Kambalda (on lake shore) mean 266.2 mm, lowest 13.7 mm (June), highest 69.5 mm (January);
- Temperature @ Kalgoorlie (60 km away) mean 25.3°C, highest 33.6°C (January), lowest 16.7°C (July);
- average number clear days is 151.1, annual average cloudy days 89.2.

Security
- Public access at the lake used for and parts used for recreational land sailing
- Secured gated compounds in some areas owned by mining companies

Communication
- Satellite phone
- Restrict areas of 3G

Permissions
- Formal request for lake areas through Department of Lands
- Mine Lease areas requires mine permissions
# Lake Lefroy Climate Data

## Temperature

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual</th>
<th>Years</th>
<th>Plot Map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean maximum temperature (°C)</td>
<td>33.7</td>
<td>32.1</td>
<td>29.4</td>
<td>25.2</td>
<td>20.7</td>
<td>17.6</td>
<td>16.8</td>
<td>18.7</td>
<td>22.3</td>
<td>25.9</td>
<td>29.0</td>
<td>32.0</td>
<td>25.3</td>
<td>75</td>
<td>1939 - 2016</td>
</tr>
<tr>
<td>Mean minimum temperature (°C)</td>
<td>18.3</td>
<td>17.9</td>
<td>16.1</td>
<td>12.7</td>
<td>8.7</td>
<td>6.2</td>
<td>5.0</td>
<td>5.7</td>
<td>8.0</td>
<td>11.2</td>
<td>14.2</td>
<td>16.6</td>
<td>11.7</td>
<td>75</td>
<td>1939 - 2016</td>
</tr>
</tbody>
</table>

## Rainfall

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual</th>
<th>Years</th>
<th>Plot Map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean rainfall (mm)</td>
<td>26.8</td>
<td>30.4</td>
<td>25.8</td>
<td>20.6</td>
<td>25.7</td>
<td>27.7</td>
<td>24.9</td>
<td>21.2</td>
<td>14.2</td>
<td>15.3</td>
<td>18.6</td>
<td>16.2</td>
<td>266.3</td>
<td>75</td>
<td>1939 - 2016</td>
</tr>
<tr>
<td>Decile 5 (median) rainfall (mm)</td>
<td>10.6</td>
<td>13.8</td>
<td>10.4</td>
<td>13.0</td>
<td>19.1</td>
<td>18.8</td>
<td>20.3</td>
<td>15.7</td>
<td>11.3</td>
<td>10.2</td>
<td>15.3</td>
<td>11.2</td>
<td>245.4</td>
<td>77</td>
<td>1939 - 2016</td>
</tr>
<tr>
<td>Mean number of days of rain ≥ 1 mm</td>
<td>2.4</td>
<td>2.9</td>
<td>2.7</td>
<td>3.3</td>
<td>4.0</td>
<td>4.9</td>
<td>4.8</td>
<td>3.9</td>
<td>2.7</td>
<td>2.7</td>
<td>2.5</td>
<td>39.7</td>
<td>77</td>
<td>1939 - 2016</td>
<td></td>
</tr>
</tbody>
</table>

## Other daily elements

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual</th>
<th>Years</th>
<th>Plot Map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean daily sunshine (hours)</td>
<td>15.7</td>
<td>13.1</td>
<td>13.4</td>
<td>10.2</td>
<td>10.3</td>
<td>9.1</td>
<td>10.1</td>
<td>12.8</td>
<td>14.1</td>
<td>13.9</td>
<td>12.9</td>
<td>15.5</td>
<td>151.1</td>
<td>72</td>
<td>1939 - 2010</td>
</tr>
<tr>
<td>Mean number of clear days</td>
<td>5.6</td>
<td>6.3</td>
<td>6.9</td>
<td>9.2</td>
<td>10.2</td>
<td>10.4</td>
<td>9.7</td>
<td>7.0</td>
<td>6.2</td>
<td>5.9</td>
<td>6.5</td>
<td>5.3</td>
<td>89.2</td>
<td>72</td>
<td>1939 - 2010</td>
</tr>
</tbody>
</table>

## 9 am conditions

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual</th>
<th>Years</th>
<th>Plot Map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean 9am temperature (°C)</td>
<td>23.8</td>
<td>22.8</td>
<td>21.0</td>
<td>17.9</td>
<td>13.9</td>
<td>11.0</td>
<td>9.9</td>
<td>11.6</td>
<td>14.8</td>
<td>17.9</td>
<td>20.6</td>
<td>22.7</td>
<td>17.3</td>
<td>72</td>
<td>1939 - 2010</td>
</tr>
<tr>
<td>Mean 9am relative humidity (%)</td>
<td>45</td>
<td>51</td>
<td>54</td>
<td>60</td>
<td>67</td>
<td>74</td>
<td>73</td>
<td>65</td>
<td>54</td>
<td>47</td>
<td>45</td>
<td>43</td>
<td>57</td>
<td>65</td>
<td>1939 - 2010</td>
</tr>
<tr>
<td>Mean 9am wind speed (km/h)</td>
<td>16.6</td>
<td>16.4</td>
<td>15.7</td>
<td>14.4</td>
<td>11.8</td>
<td>11.8</td>
<td>12.4</td>
<td>14.3</td>
<td>16.2</td>
<td>17.1</td>
<td>17.1</td>
<td>16.3</td>
<td>15.0</td>
<td>72</td>
<td>1939 - 2010</td>
</tr>
</tbody>
</table>

## 3 pm conditions

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual</th>
<th>Years</th>
<th>Plot Map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean 3pm temperature (°C)</td>
<td>32.3</td>
<td>30.9</td>
<td>28.6</td>
<td>24.3</td>
<td>19.9</td>
<td>16.8</td>
<td>16.0</td>
<td>17.8</td>
<td>21.3</td>
<td>24.7</td>
<td>27.8</td>
<td>30.7</td>
<td>24.3</td>
<td>72</td>
<td>1939 - 2010</td>
</tr>
<tr>
<td>Mean 3pm relative humidity (%)</td>
<td>24</td>
<td>30</td>
<td>32</td>
<td>38</td>
<td>44</td>
<td>48</td>
<td>46</td>
<td>39</td>
<td>31</td>
<td>27</td>
<td>25</td>
<td>24</td>
<td>34</td>
<td>65</td>
<td>1939 - 2010</td>
</tr>
<tr>
<td>Mean 3pm wind speed (km/h)</td>
<td>15.1</td>
<td>15.1</td>
<td>14.2</td>
<td>13.7</td>
<td>14.1</td>
<td>15.7</td>
<td>16.6</td>
<td>17.2</td>
<td>17.8</td>
<td>17.6</td>
<td>17.2</td>
<td>16.0</td>
<td>15.9</td>
<td>72</td>
<td>1939 - 2010</td>
</tr>
</tbody>
</table>
Lake Lefroy 10 year Temporal Means VNIR-SWIR
Lake Lefroy 10 Year Temporal Means VNIR
Lake Lefroy 10 Year Temporal Means SWIR
Lake Lefrov temporal variations (coefficient of variation) VNIR
Lake Lefroy temporal variations (coefficient of variation) VNIR-SWIR
Pinnacles Desert Location And Logistics

Access
- Lat Lon: 30°35'24.67"S, 115° 9'23.84"E, elevation 30-70 m
- ~ 250 km N of Perth
- Nearest airport Perth
- Nearest town and accommodation Cervantes, ~20 km away
- Sealed roads all the way from Perth to Nambung National Park
- ~ 1 km walk into sand dunes

Landform
- Undulating sand dunes of 2X5km consisting dominantly of quartz, carbonate, kaolinite, and minor amounts of iron oxide

Vegetation
- Low dry heathlands, 170 angiosperms: eg. coastal wattle, sea nymph, acorn banksia, cowslip orchid, ringed wallaby grass and coast hop-bush. 1 gymnosperm: swamp cypress
Pinnacles Desert Location And Logistics

Communications
- 3 / 4 G
- Satellite
- Landline

Permissions
- Department of Parks and Wildlife
- Aboriginal Heritage
- Need to minimise disturbance especially if on dunes
- Bitumised, locked up areas around the Discovery Centre

Security
- Dunes are in Nambung National Park
- Dunes are at least 1 km from tourist traffic area, no tracks except for animals (Emu and Kangaroos) in 7 visits
- Park is manned by rangers
## Pinnacles Desert Met Data From Nearest Met Station

### Statistics

#### Temperature

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual</th>
<th>Years</th>
<th>Plot</th>
<th>Map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean maximum temperature (°C)</td>
<td>30.0</td>
<td>30.9</td>
<td>29.5</td>
<td>26.4</td>
<td>23.2</td>
<td>20.7</td>
<td>19.5</td>
<td>20.0</td>
<td>21.3</td>
<td>23.4</td>
<td>25.9</td>
<td>28.2</td>
<td>24.9</td>
<td>46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean minimum temperature (°C)</td>
<td>17.2</td>
<td>18.0</td>
<td>18.6</td>
<td>16.0</td>
<td>11.8</td>
<td>10.3</td>
<td>9.3</td>
<td>9.4</td>
<td>10.0</td>
<td>11.3</td>
<td>13.5</td>
<td>15.6</td>
<td>13.1</td>
<td>46</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Rainfall

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual</th>
<th>Years</th>
<th>Plot</th>
<th>Map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean rainfall (mm)</td>
<td>6.5</td>
<td>14.3</td>
<td>14.0</td>
<td>29.1</td>
<td>78.4</td>
<td>104.5</td>
<td>112.3</td>
<td>80.7</td>
<td>44.5</td>
<td>25.7</td>
<td>18.2</td>
<td>7.1</td>
<td>532.9</td>
<td>46</td>
<td>1968</td>
<td>2015</td>
</tr>
<tr>
<td>Decile 5 (median) rainfall (mm)</td>
<td>1.0</td>
<td>3.0</td>
<td>6.8</td>
<td>10.7</td>
<td>71.9</td>
<td>102.8</td>
<td>110.6</td>
<td>82.0</td>
<td>41.8</td>
<td>23.5</td>
<td>13.4</td>
<td>3.3</td>
<td>563.4</td>
<td>46</td>
<td>1968</td>
<td>2018</td>
</tr>
<tr>
<td>Mean number of days of rain ≥ 1 mm</td>
<td>0.9</td>
<td>1.3</td>
<td>1.8</td>
<td>4.4</td>
<td>9.0</td>
<td>11.6</td>
<td>13.4</td>
<td>11.3</td>
<td>8.2</td>
<td>4.8</td>
<td>3.4</td>
<td>1.3</td>
<td>71.4</td>
<td>47</td>
<td>1968</td>
<td>2015</td>
</tr>
</tbody>
</table>

#### Other daily elements

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual</th>
<th>Years</th>
<th>Plot</th>
<th>Map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean daily sunshine (hours)</td>
<td>16.0</td>
<td>13.4</td>
<td>13.3</td>
<td>9.9</td>
<td>8.4</td>
<td>7.3</td>
<td>7.4</td>
<td>7.8</td>
<td>8.7</td>
<td>10.5</td>
<td>11.3</td>
<td>14.6</td>
<td>128.7</td>
<td>41</td>
<td>1969</td>
<td>2010</td>
</tr>
<tr>
<td>Mean number of clear days</td>
<td>5.2</td>
<td>5.1</td>
<td>6.8</td>
<td>9.1</td>
<td>11.9</td>
<td>12.9</td>
<td>13.3</td>
<td>12.0</td>
<td>9.7</td>
<td>8.6</td>
<td>7.4</td>
<td>5.4</td>
<td>107.4</td>
<td>41</td>
<td>1969</td>
<td>2010</td>
</tr>
<tr>
<td>Mean number of cloudy days</td>
<td>5.8</td>
<td>5.3</td>
<td>7.2</td>
<td>10.9</td>
<td>15.0</td>
<td>15.0</td>
<td>15.7</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
</tr>
</tbody>
</table>

#### 9 am conditions

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual</th>
<th>Years</th>
<th>Plot</th>
<th>Map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean 9am temperature (°C)</td>
<td>25.2</td>
<td>25.2</td>
<td>23.7</td>
<td>20.6</td>
<td>17.4</td>
<td>14.9</td>
<td>13.9</td>
<td>14.6</td>
<td>16.7</td>
<td>19.1</td>
<td>21.8</td>
<td>23.9</td>
<td>19.8</td>
<td>41</td>
<td>1969</td>
<td>2010</td>
</tr>
<tr>
<td>Mean 9am relative humidity (%)</td>
<td>58</td>
<td>57</td>
<td>59</td>
<td>64</td>
<td>70</td>
<td>75</td>
<td>77</td>
<td>73</td>
<td>68</td>
<td>61</td>
<td>58</td>
<td>56</td>
<td>64</td>
<td>38</td>
<td>1969</td>
<td>2010</td>
</tr>
<tr>
<td>Mean 9am wind speed (km/h)</td>
<td>19.4</td>
<td>18.7</td>
<td>16.9</td>
<td>15.4</td>
<td>15.1</td>
<td>16.2</td>
<td>16.5</td>
<td>17.0</td>
<td>16.6</td>
<td>17.6</td>
<td>18.3</td>
<td>19.2</td>
<td>17.2</td>
<td>40</td>
<td>1969</td>
<td>2010</td>
</tr>
</tbody>
</table>

#### 9am wind speed vs direction plot

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual</th>
<th>Years</th>
<th>Plot</th>
<th>Map</th>
</tr>
</thead>
</table>

#### 3 pm conditions

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual</th>
<th>Years</th>
<th>Plot</th>
<th>Map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean 3pm temperature (°C)</td>
<td>26.4</td>
<td>27.2</td>
<td>26.5</td>
<td>24.3</td>
<td>21.7</td>
<td>19.4</td>
<td>18.3</td>
<td>18.6</td>
<td>19.7</td>
<td>21.1</td>
<td>23.0</td>
<td>24.8</td>
<td>22.8</td>
<td>41</td>
<td>1969</td>
<td>2010</td>
</tr>
<tr>
<td>Mean 3pm relative humidity (%)</td>
<td>59</td>
<td>58</td>
<td>58</td>
<td>59</td>
<td>61</td>
<td>63</td>
<td>65</td>
<td>62</td>
<td>62</td>
<td>60</td>
<td>59</td>
<td>59</td>
<td>61</td>
<td>38</td>
<td>1969</td>
<td>2010</td>
</tr>
<tr>
<td>Mean 3pm wind speed (km/h)</td>
<td>29.3</td>
<td>26.7</td>
<td>24.2</td>
<td>20.0</td>
<td>17.5</td>
<td>18.1</td>
<td>18.7</td>
<td>19.4</td>
<td>20.6</td>
<td>24.1</td>
<td>26.4</td>
<td>28.8</td>
<td>22.8</td>
<td>40</td>
<td>1969</td>
<td>2010</td>
</tr>
</tbody>
</table>

#### 3pm wind speed vs direction plot

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual</th>
<th>Years</th>
<th>Plot</th>
<th>Map</th>
</tr>
</thead>
</table>
Pinnacles Desert MgOH (Carbonate) Abundances
Pinnacles Desert Silica (Sand) Abundance
Pinnacles Desert AlO\textsubscript{2}OH Clay Abundances
Pinnacles Desert 10 year Temporal Means VNIR
Pinnacles Desert 10 year Temporal Means SWIR
Pinnacles Desert Coefficient Of Variation VNIR-SWIR
Pinnacles Desert DEM
Esperance Wylie Bay Location And Logistics

Access

• Lat Lon: 33°56'11.73"S, 122°30'8.89"E
• 727 km South of Perth
• Nearest airport: Esperance
• Nearest town and accommodation: Esperance, ~14 km away
• Sealed roads all the way from Perth to entrance of beach, then 4WD onto beach and sand dunes

Landform

• High and expansive sand dunes (1X1.5km) consisting dominantly of quartz, carbonate, kaolinite, and very minor amounts of iron oxide
Esperance Wylie Bay  Desert Location And Logistics

Vegetation
• Coastal vegetation

Communications
• 3 / 4 G?
• Satellite

Permissions
• Department of Parks and Wildlife?
• Aboriginal Heritage
• Need to minimise disturbance especially if on dunes

Security
• Dunes are in local beach where 4WD may be occurring
• Security of instruments may be an issue as it is quite a popular 4WD area
Esperance Wylie Bay Silica Abundance
Esperance Wylie Bay Carbonate Abundance
Esperance Wylie Bay Clay Abundance
Esperance Wylie Bay 10 Year Temporal Means VNIR-SWIR
Esperance Wylie Bay 10 Temporal Means VNIR
Esperance Wylie Bay 10 Temporal Means SWIR
Esperance Wylie Bay 10 Year Temporal Coefficient Of Variation
Esperance Wylie Bay DEM
Central Desert Logistics

Access

- ~ 700 km N of Adelaide
- Sealed roads from Adelaide to Lyndhurst (~600km N), good unsealed road to Marree (~80km N), good unsealed road to Muloorina Station (~80km N), unsealed tracked to site (~50-80km E).
Central Desert Logistics

Access
- Nearest airport Olympic Dam, ~150 km away;
- Nearest town and accommodation Maree, ~100 km away;
- Nearest accommodation Muloorina Station, ~50 km but now mainly used by BHPBilliton;
- Supplies including drinking water and food best obtained from Adelaide;

Landforms
- Lake Eyre covers 144kmX77km, 15.2 metres below sea level, it is the lowest point in Australia. Flood waters cover lake once every 8 years on average, filled to capacity 3X in the last 160 years;
- Surrounding area covered by red sand dunes and mesas, rising from salty claypans and stone-strewn (coarse gibber) tablelands;

Vegetation
- Vegetation is generally sparse. Canegrass and scattered clumps of mulga and acacias grow on the red sand dunes and the occasional stand of acacia can be seen on the coarse gibber tablelands. Nitre-bush, samphire, needlebush and native willow are also found in the Lake Eyre area.
- Other areas are grazed and there are an abundance of cattle in some parts of the landscape. NB. Risk of animals for instruments
Central Desert Logistics

Communications

- No communication except for satellite even at Marree which had broad band reduced;
- Satellite phone essential;

Permissions

- Large areas which are sand plains are now on BHPBilliton lease area behind gated compounds, permissions required from BHPBilliton. Keys available from Moorlina Station owners but permissions needed prior to this;
- Other areas require permissions from land managers which are either pastoralists or government land managers as the area is with the Kati Thanda-Lake Eyre National Park;
- Aboriginal heritage permissions will most likely also be required to install instruments if on nature reserve:
## Lake Eyre Climate Data

<table>
<thead>
<tr>
<th></th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>December</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean max temp (°C)</strong></td>
<td>38</td>
<td>36.8</td>
<td>33.9</td>
<td>28.5</td>
<td>23.2</td>
<td>19.6</td>
<td>19.1</td>
<td>21.5</td>
<td>25.8</td>
<td>29.6</td>
<td>33.3</td>
<td>36.1</td>
<td>28.8</td>
</tr>
<tr>
<td><strong>Highest max temp (°C)</strong></td>
<td>49.4</td>
<td>47.9</td>
<td>46.1</td>
<td>40.1</td>
<td>34</td>
<td>30.1</td>
<td>29.6</td>
<td>35</td>
<td>39.5</td>
<td>43.7</td>
<td>47.4</td>
<td>49</td>
<td>49.4</td>
</tr>
<tr>
<td><strong>Lowest max temp (°C)</strong></td>
<td>18.9</td>
<td>19</td>
<td>18</td>
<td>13.4</td>
<td>12.1</td>
<td>10.6</td>
<td>10.4</td>
<td>11.1</td>
<td>11.6</td>
<td>12.9</td>
<td>17.2</td>
<td>21.4</td>
<td>10.4</td>
</tr>
<tr>
<td><strong>Mean rainfall (mm)</strong></td>
<td>176</td>
<td>203.3</td>
<td>178.6</td>
<td>215.9</td>
<td>72.8</td>
<td>86.1</td>
<td>53.9</td>
<td>75.9</td>
<td>83.7</td>
<td>69.7</td>
<td>78</td>
<td>107.5</td>
<td>408.7</td>
</tr>
<tr>
<td><strong>Highest rainfall (mm)</strong></td>
<td>186</td>
<td>203.3</td>
<td>178.6</td>
<td>215.9</td>
<td>72.8</td>
<td>86.1</td>
<td>53.9</td>
<td>75.9</td>
<td>83.7</td>
<td>69.7</td>
<td>78</td>
<td>107.5</td>
<td>408.7</td>
</tr>
<tr>
<td><strong>Lowest rainfall (mm)</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Mean number of cloudy days</strong></td>
<td>4.2</td>
<td>4.2</td>
<td>3.3</td>
<td>4.1</td>
<td>5.8</td>
<td>5.5</td>
<td>5.3</td>
<td>3.8</td>
<td>3.8</td>
<td>4.7</td>
<td>4.9</td>
<td>5.3</td>
<td>54.9</td>
</tr>
<tr>
<td><strong>Mean 9am relative humidity (%)</strong></td>
<td>34</td>
<td>41</td>
<td>40</td>
<td>48</td>
<td>62</td>
<td>71</td>
<td>69</td>
<td>58</td>
<td>47</td>
<td>40</td>
<td>36</td>
<td>34</td>
<td>41</td>
</tr>
<tr>
<td><strong>Mean 3pm relative humidity (%)</strong></td>
<td>21</td>
<td>26</td>
<td>25</td>
<td>31</td>
<td>39</td>
<td>44</td>
<td>41</td>
<td>34</td>
<td>29</td>
<td>25</td>
<td>23</td>
<td>21</td>
<td>30</td>
</tr>
</tbody>
</table>
Desert temporal means and coefficient of variations (VNIR-SWIR)
Central Desert 10 Year Temporal Means VNIR
Central Desert 10 Year Temporal Means SWIR
Central Desert DEM
Other information on thumb drive

- Photos and accompanying spectra;
- View Spec Pro for viewing spectra;
- Hyperion data (unprocessed!)
1. A high-reflectance results in higher signal-to-noise ratio (SNR) which, in return, increases overall accuracy.
2. The higher the spatial uniformity of the area, the lesser the effects of generalizing the reflectance data to the size of the full test site.
3. Spectral uniformity of the site eases the calibration procedure.
4. Temporal uniformity of the site eases the calibration procedure.
5. The site should have little or no vegetation that can deteriorate spectral and temporal uniformity.
6. Higher elevation reduces the error due to aerosols.
7. A Lambertian site surface is preferable since it decreases errors caused by different solar and view geometry.
8. High probability of cloud free days provides more time for calibration studies.
9. A longer distance to densely populated areas and/or industrial facilities decreases the effect of anthropogenic aerosols.
10. A location far from the seas or other large water bodies minimizes the influence of atmospheric water vapor.
11. Having a site in an arid region minimizes probability of precipitation and this in turn may change the surface BRDF. Also, in arid regions, the probability of a cloudy weather is minimum.
12. Having a large site minimizes the unwanted effects of scattering of light from areas outside the target area.
13. Easy access to the site is an advantage.
14. Instrumented test sites are preferable.