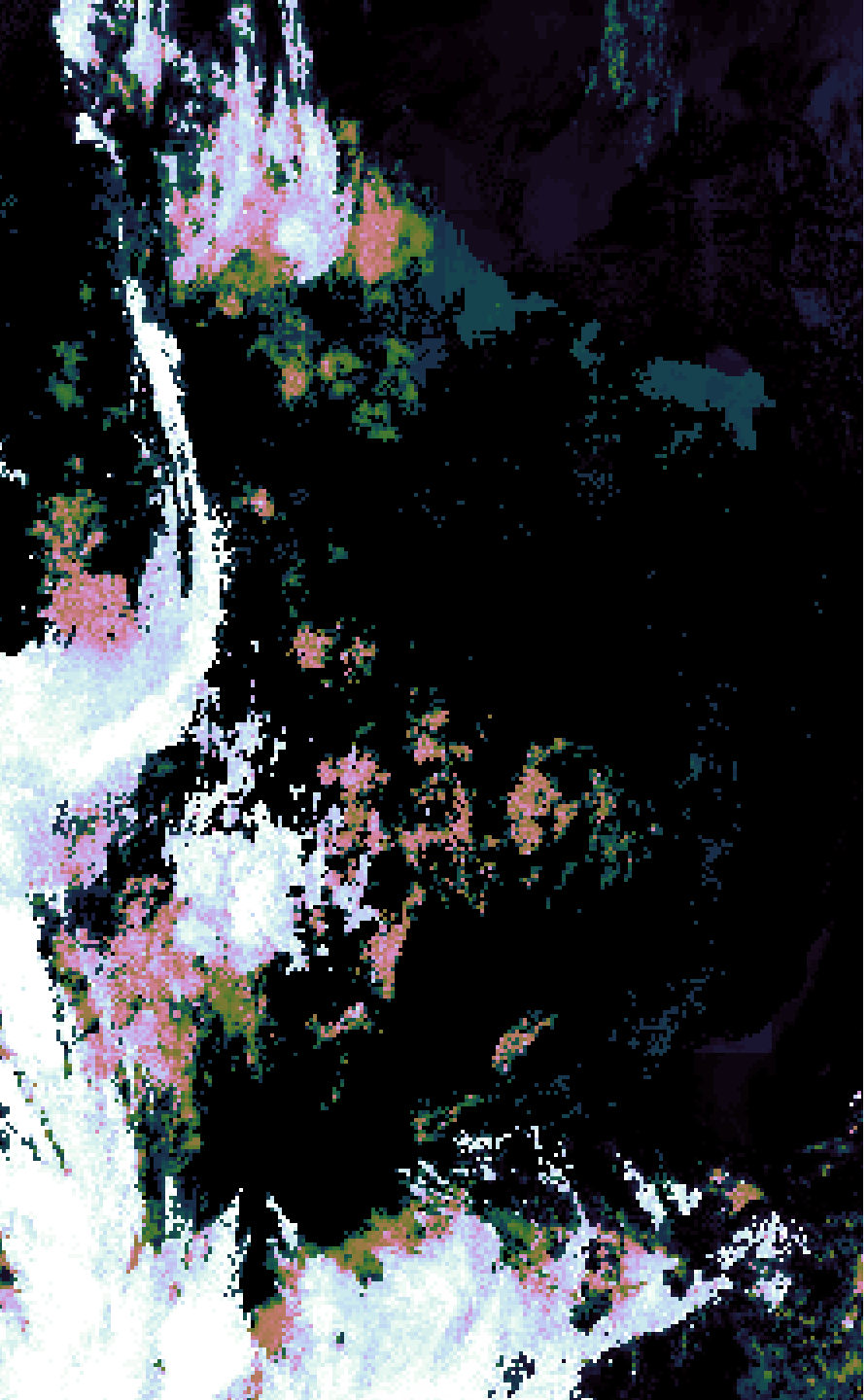


Quantifying Potential Sites for Imaging Air Cherenkov Telescopes in Australia

Paddy McGee, Sabrina Einecke

THE UNIVERSITY of ADELAIDE

CTA-Oz Meeting
April 16th, 2020

What we're doing

- List of possible sites for a small array of IACT to be used for monitoring/follow-up
- Requirements similar to those for optical telescopes (e.g. need clear skies, not too much wind, but high elevation may or may not be a primary factor, depending on results from Simon's simulations)
- Determine general conditions at each site
  - weather conditions
  - altitude
  - night-sky brightness
  - proximity to services (e.g. SSO very good, some others have mains power but not close to major centres or tech support, some are remote with no facilities at all).

- Not making a decision, just a survey at this stage

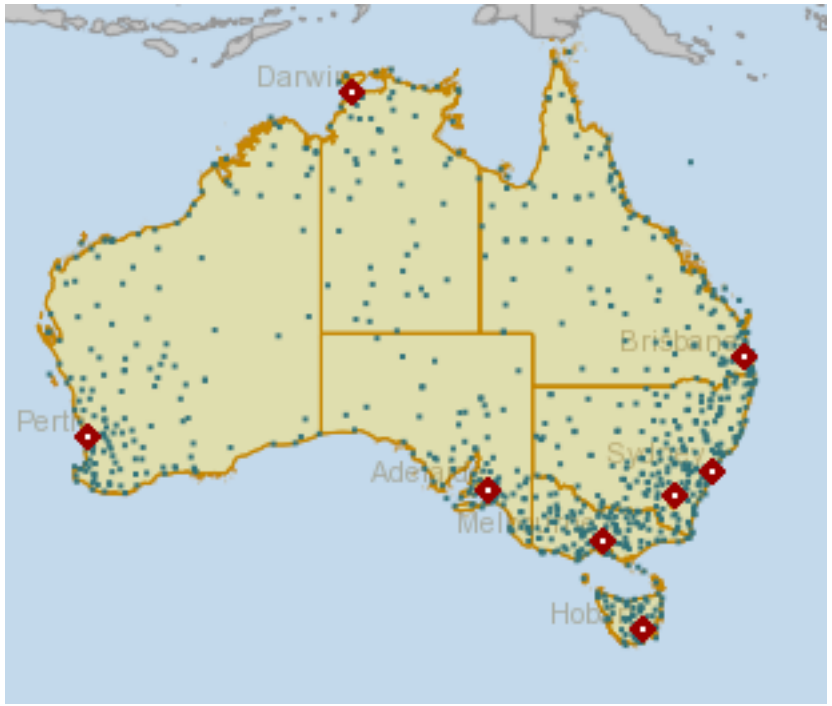
Bureau of Meteorology

Australian Government
Bureau of Meteorology

- Provides history of weather and climate data
  - Rainfall
  - Temperature
  - Frost, evaporation, humidity
  - Wind
  - Cyclones & thunderstorms
  - …

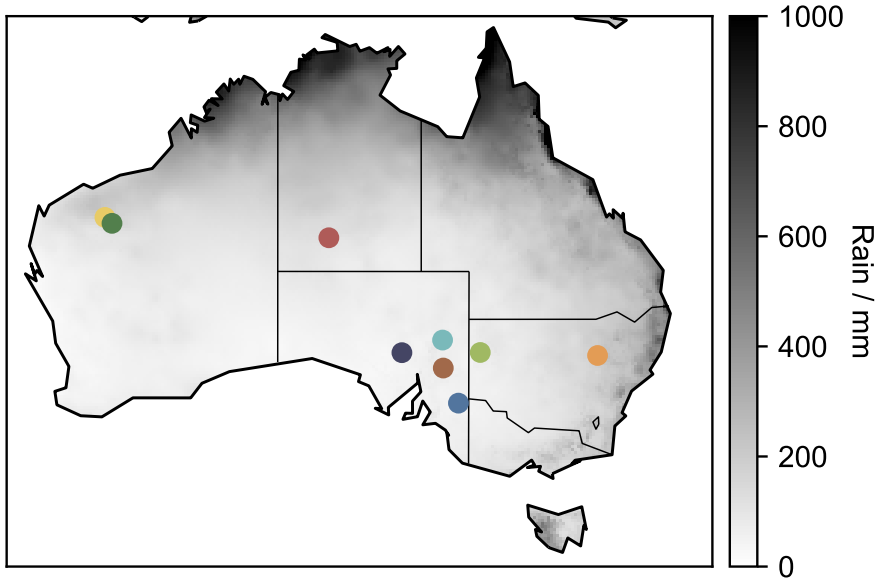
- Many data provided as gridded products
  —> Precise data for each site can be extracted

Weather Stations



http://www.bom.gov.au/climate/averages/maps.shtml

- Locations from east to west

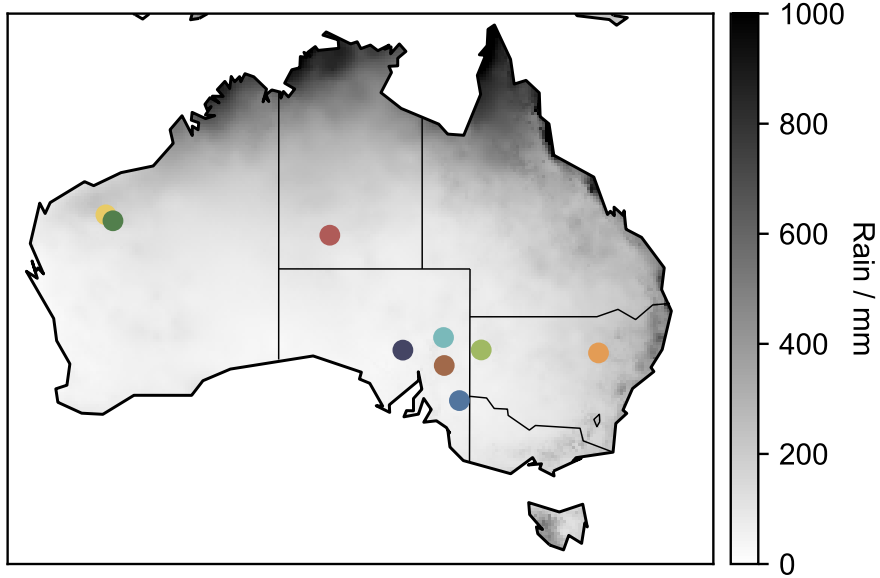


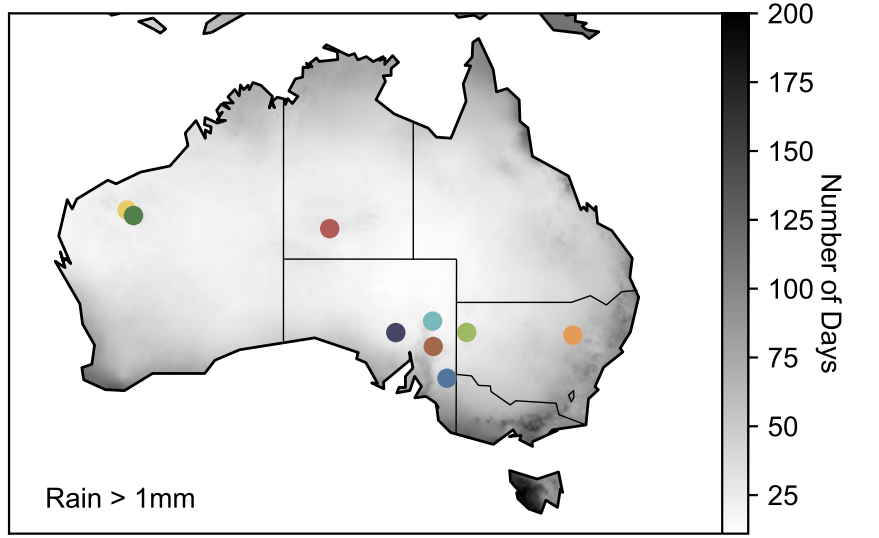
- Siding Spring / Mopra (alt. ~ 820m - 1140m)
- UNSW Fowler's Gap (alt. ~ 180m - 200m)
- Moorook (alt. ~40m)
- Koonamore (alt. ~ 200m - 300m)
- Arkaroola (alt. ~ 330m - 500m)
- Woomera (alt. ~ 164m)
- MacDonnell Ranges / Mereenie (alt. ~ 720m - 1000m)
- Hammersley Ranges / Mt. Meharry (~ 840m - 1200m), Mt. Bruce (~700m - 1200m)

Rain

- Average rainfall over the period 1961 to 1990
- Annual, seasonal and monthly rainfall information available as gridded product
- Number of days with rain over 1, 2, 3, 5, 10, 25mm available, e.g. to identify regions and seasons of heavy rain

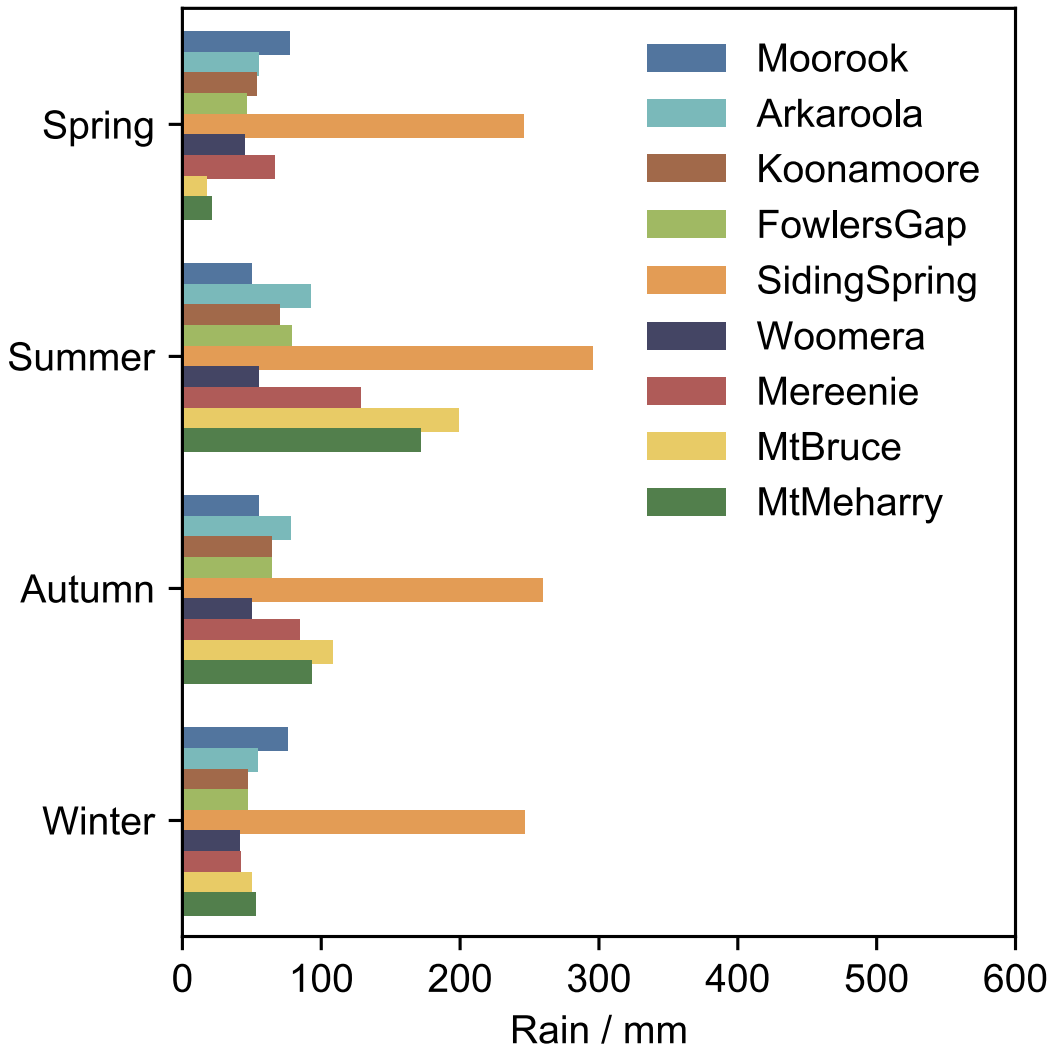
- Central Australia: Very dry, rainfall highly variable, only few days of rain
- Towards coast: Increased rainfall
- Northern Australia: Monsoons during summer months
- Southern Australia: Most rainfall during winter months, associated with frontal systems

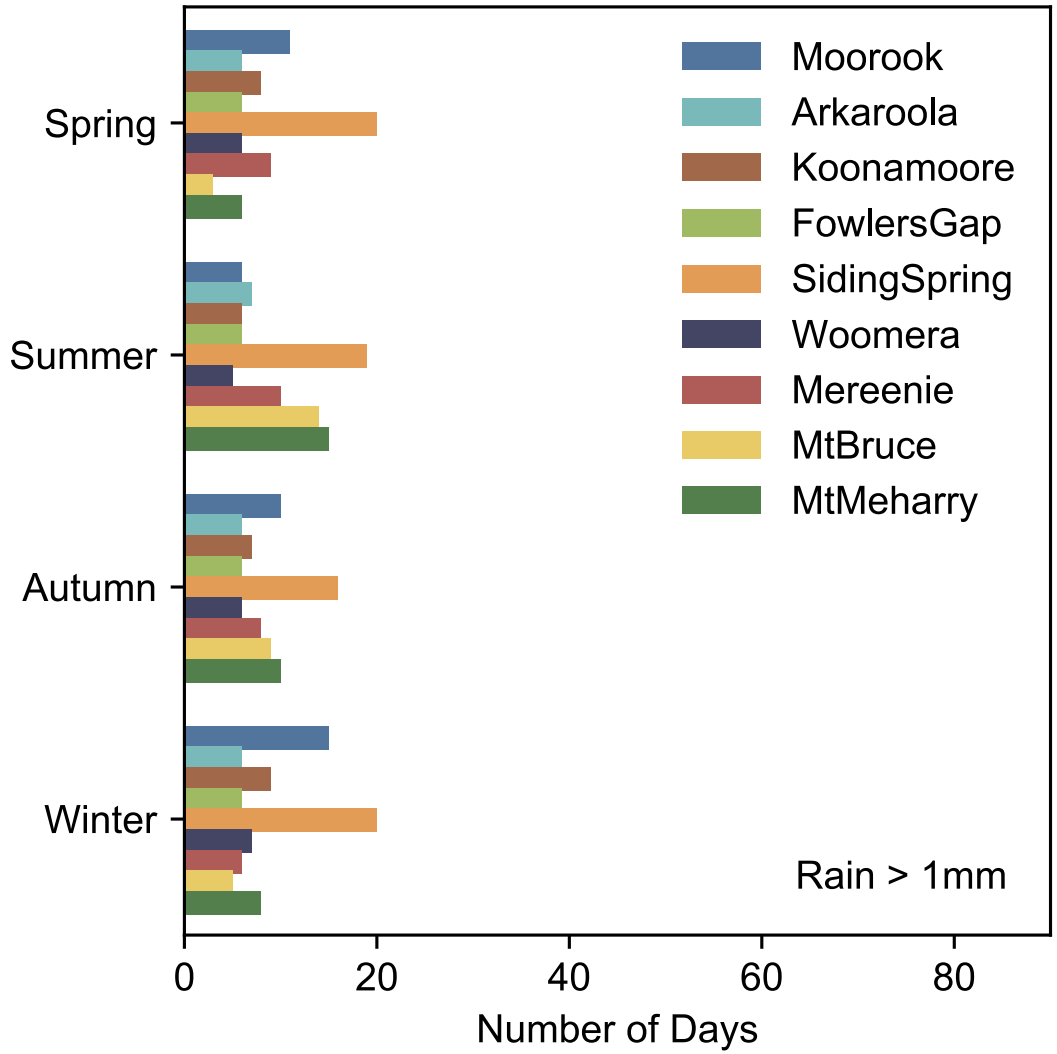




http://www.bom.gov.au/jsp/ncc/climate_averages/rainfall/index.jsp

Rain


Spring
Summer
Autumn
Winter
Moorook
Arkaroola
Koonamoore
FowlersGap
SidingSpring
Woomera
Mereenie
MtBruce
MtMeharry
0
100
200
300
400
500
600
Rain / mm

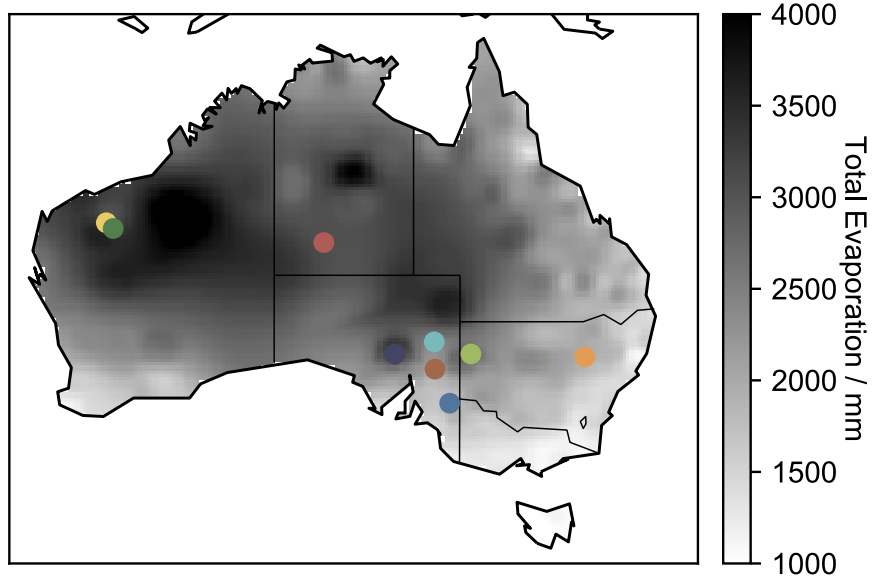

Spring
Summer
Autumn
Winter
Moorook
Arkaroola
Koonamoore
FowlersGap
SidingSpring
Woomera
Mereenie
MtBruce
MtMeharry
Rain > 1mm
0
20
40
60
80
Number of Days

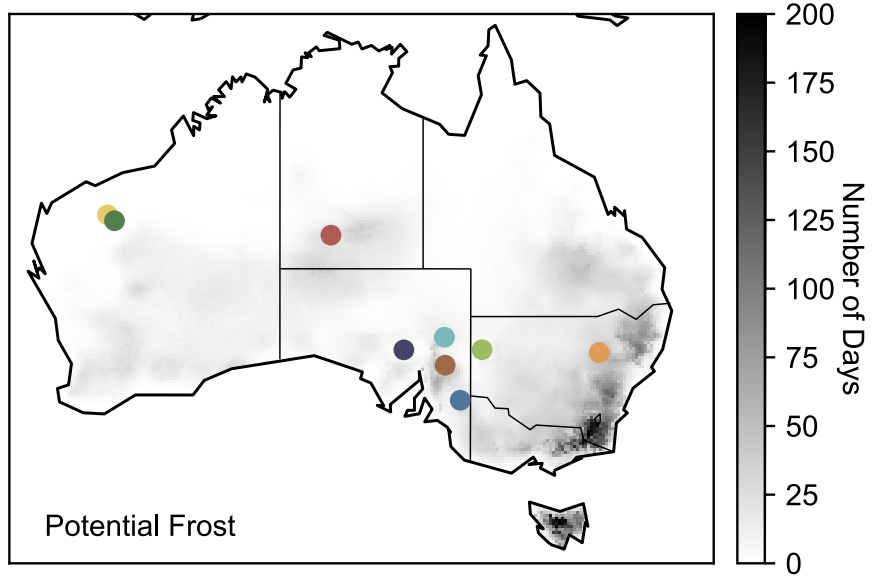
Evaporation and Frost

- Average amount of water evaporating from an open pan based on at least 10 years records from 1975 to 2005
- Rate of evaporation depends on factors such as cloudiness, air temperature and wind speed
- Annual, seasonal and monthly rainfall information available as gridded product

- Average potential frost over a period from 1976 to 2005
- Potential frost: When minimum temperature below a specific threshold

- Central Australia: High rate of evaporation (due to dryness)
- Coastal regions: Low rate of evaporation (due to proximity to water)

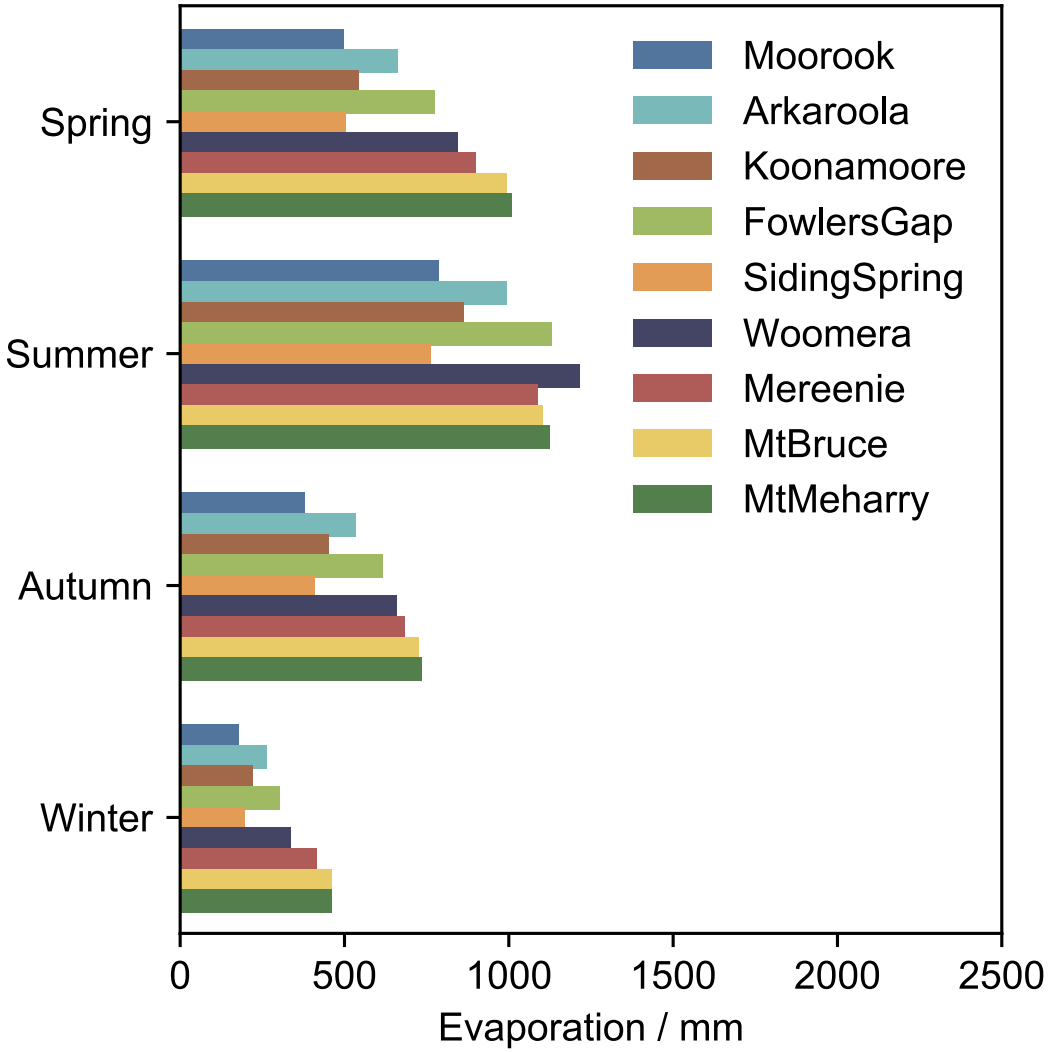


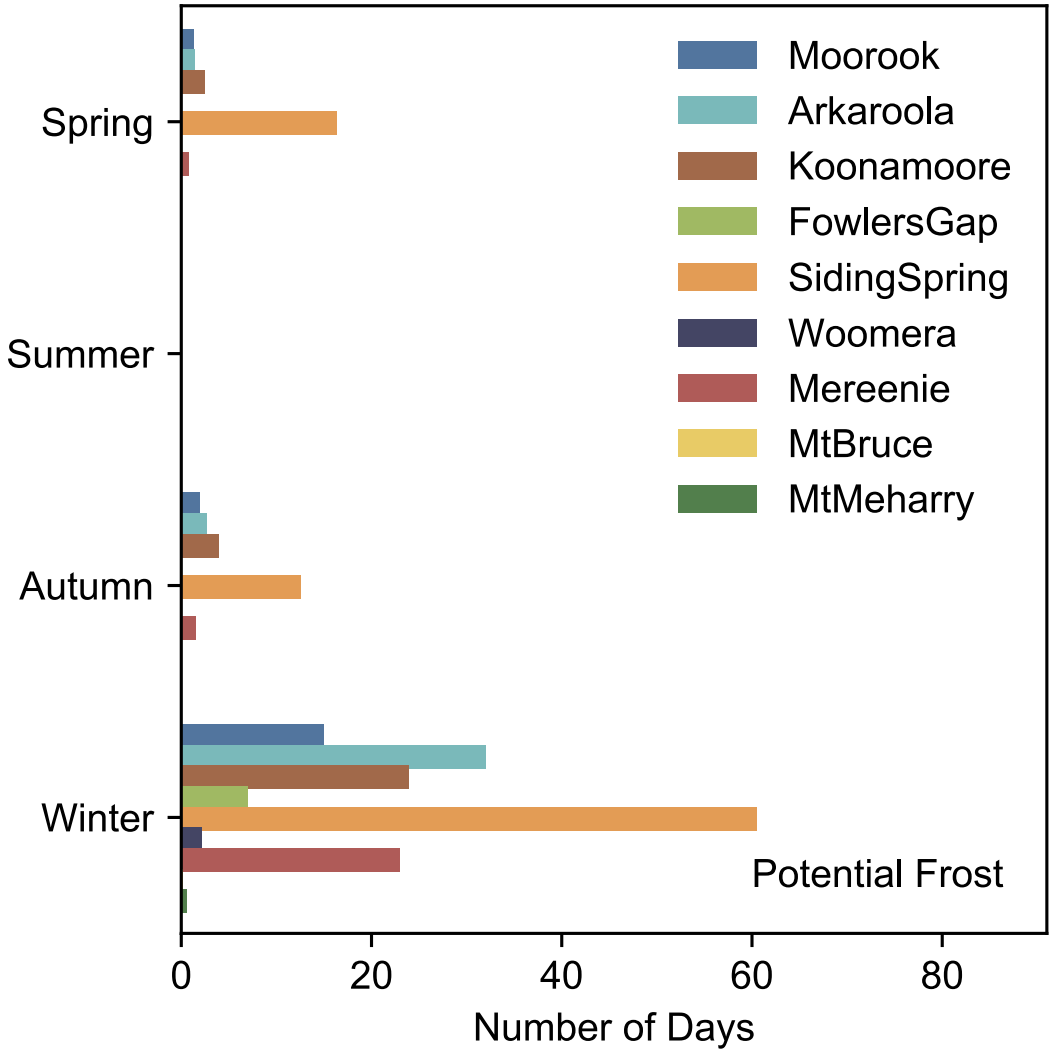


http://www.bom.gov.au/jsp/ncc/climate_averages/evaporation/index.jsp

http://www.bom.gov.au/jsp/ncc/climate_averages/frost/index.jsp

Evaporation and Frost

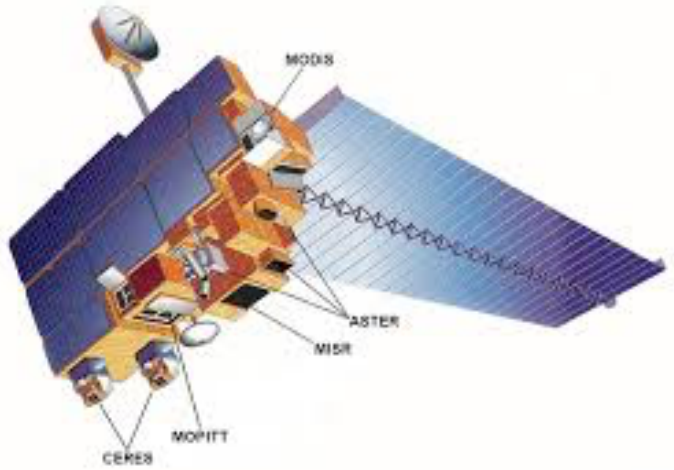




MODIS

- MODIS: Moderate Resolution Imaging Spectroradiometer
- Aboard the Terra and Aqua satellites
- Terra orbiting from north to south across equator in the morning
- Aqua orbiting from south to north across equator in afternoon
- Terra and Aqua viewing Earth's surface every 1 to 2 days

- 36 spectral bands from 0.4 to 14.4µm
- 2 bands at resolution of 250m
- 5 bands at resolution of 500m
- 29 bands at resolution of 1km



https://modis.gsfc.nasa.gov

MODIS Cloud Product

- Combination of infrared and visible techniques
- Determination of physical and radiative cloud properties
- Daily global Level 2 data provided

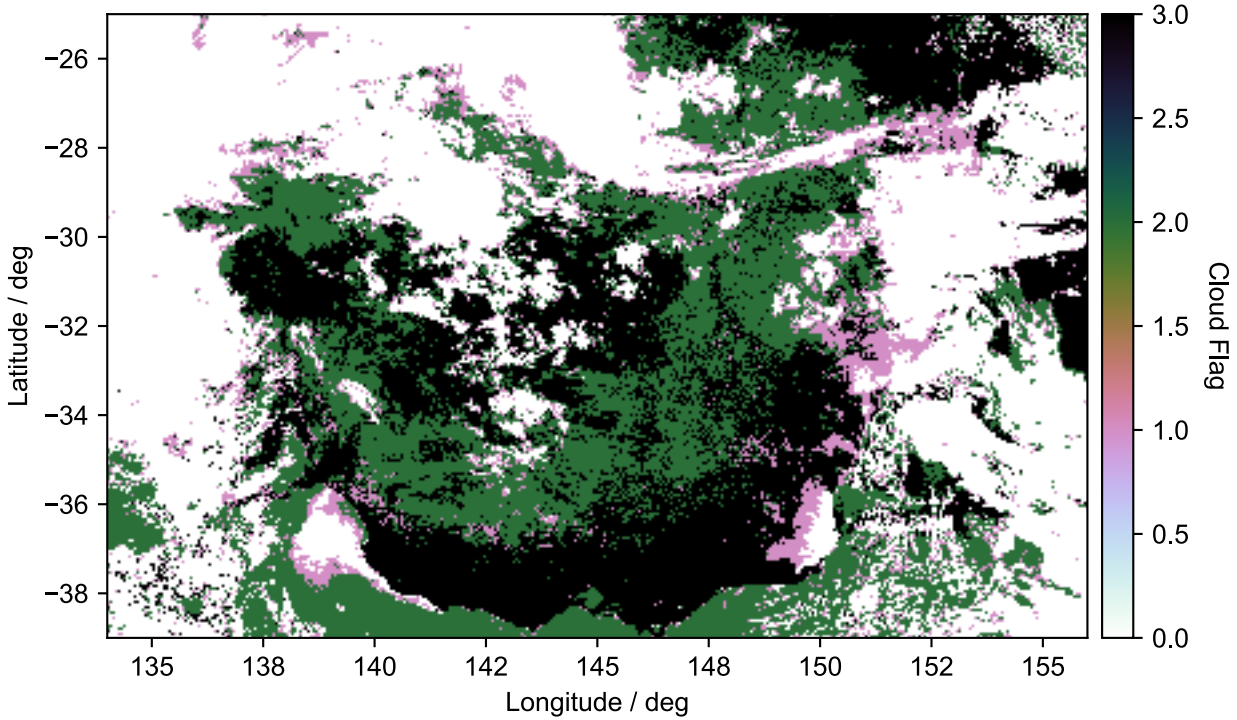
- Daytime only: cloud particle phase, cloud optical thickness using near-infrared and mid-wave infrared channel
- Day and night: Cloud top temperature, height, emissivity and cloud fraction using infrared-only methods

https://modis.gsfc.nasa.gov/data/dataprod/mod06.php

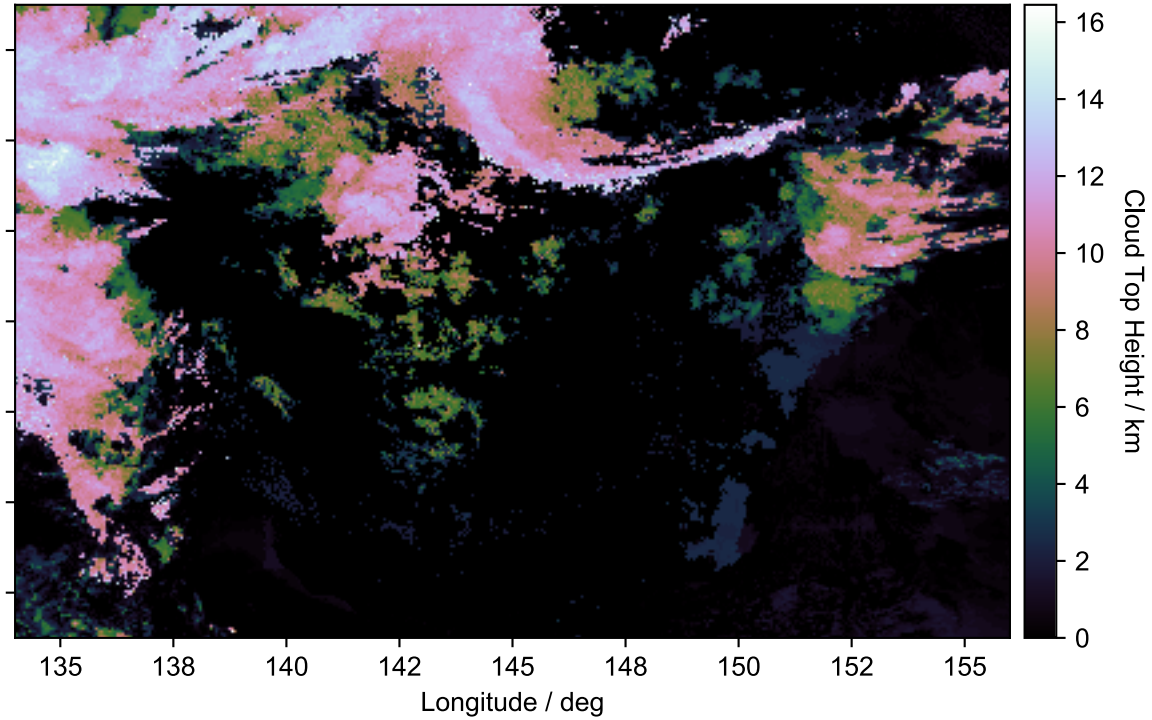
MODIS Cloud Product

Examples

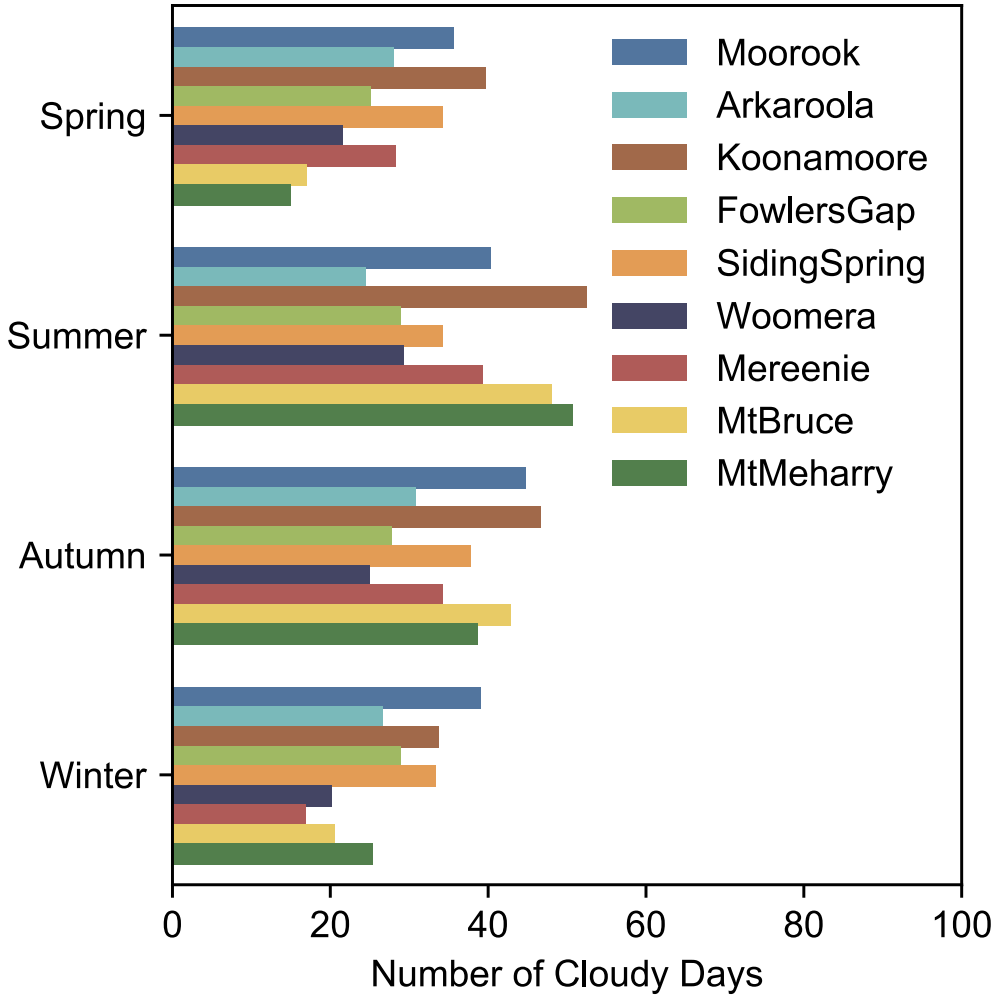
CLOUD FLAG
3 = cloud, 2 = probably cloud,
0 = clear, 1 = probably clear

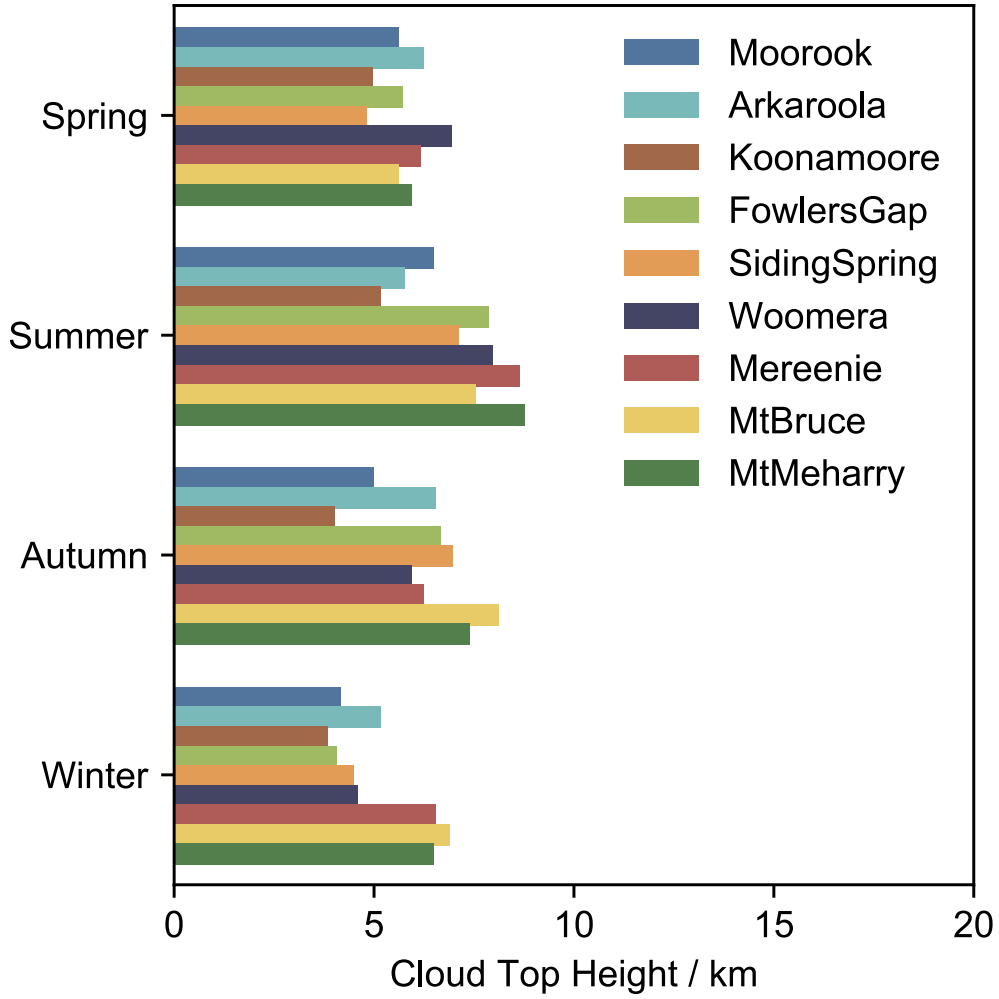


CLOUD TOP HEIGHT
As expected, same structure as cloud flag



Clouds


Spring
Summer
Autumn
Winter
Moorook
Arkaroola
Koonamoore
FowlersGap
SidingSpring
Woomera
Mereenie
MtBruce
MtMeharry
0
20
40
60
80
100
Number of Cloudy Days


Spring
Summer
Autumn
Winter
Moorook
Arkaroola
Koonamoore
FowlersGap
SidingSpring
Woomera
Mereenie
MtBruce
MtMeharry
0
5
10
15
20
Cloud Top Height / km

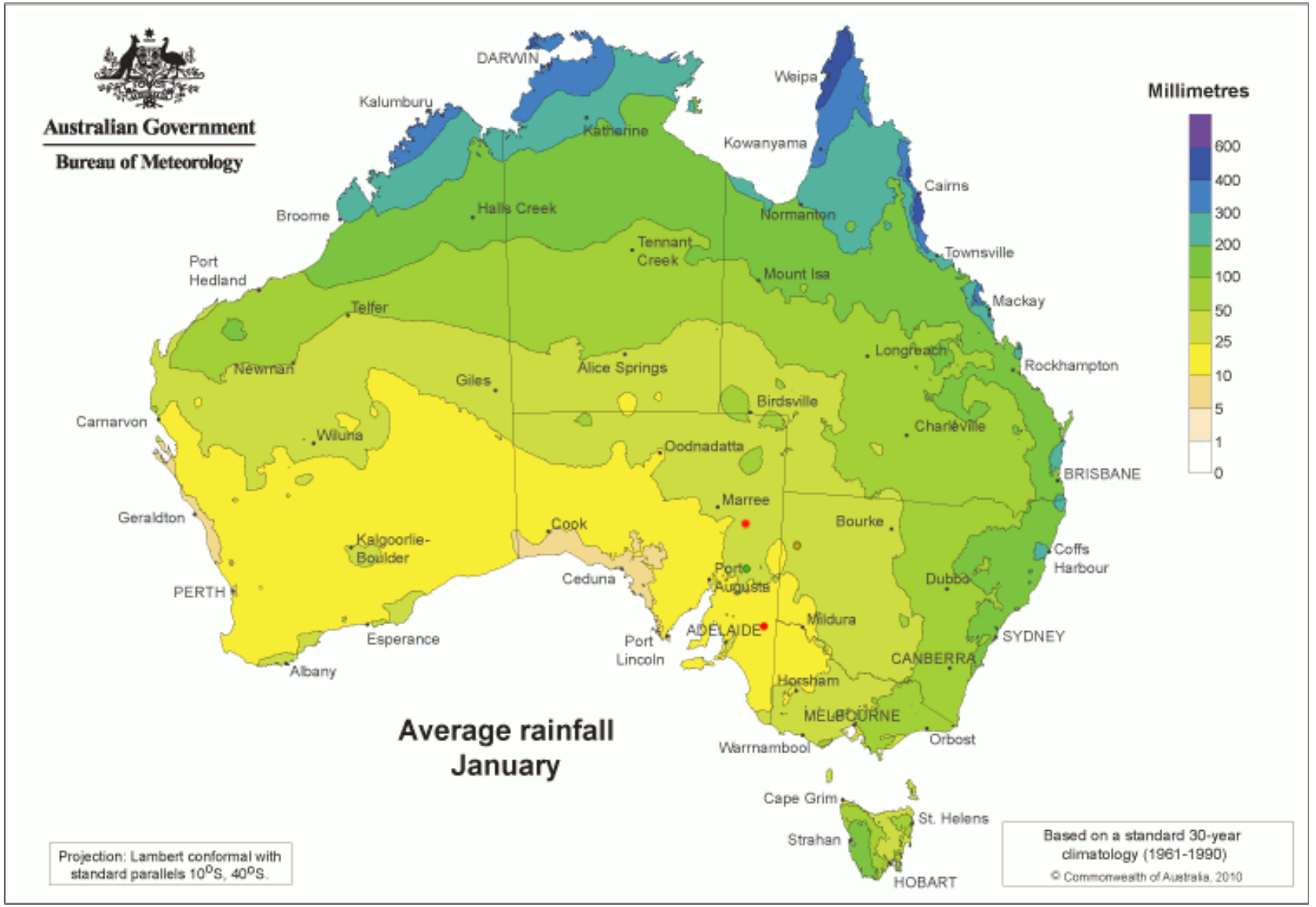
BoM-supplied climate maps

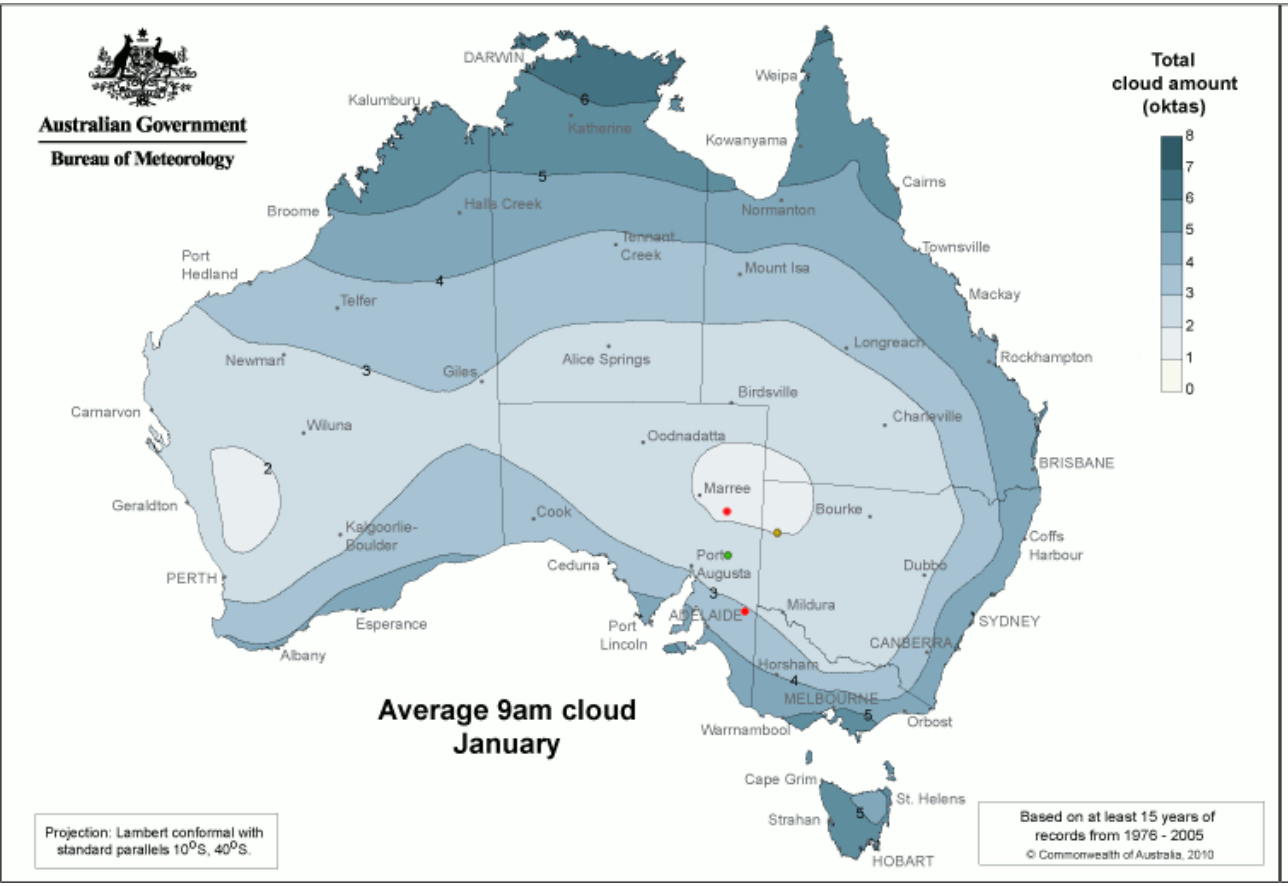
- The BoM provides some long-term climate maps based on these data.
- Generally presented as iso-value maps
- e.g. rainfall by month
- e.g. oktas of cloud at 9 a.m. and 3 p.m.
- e.g. lightning strikes

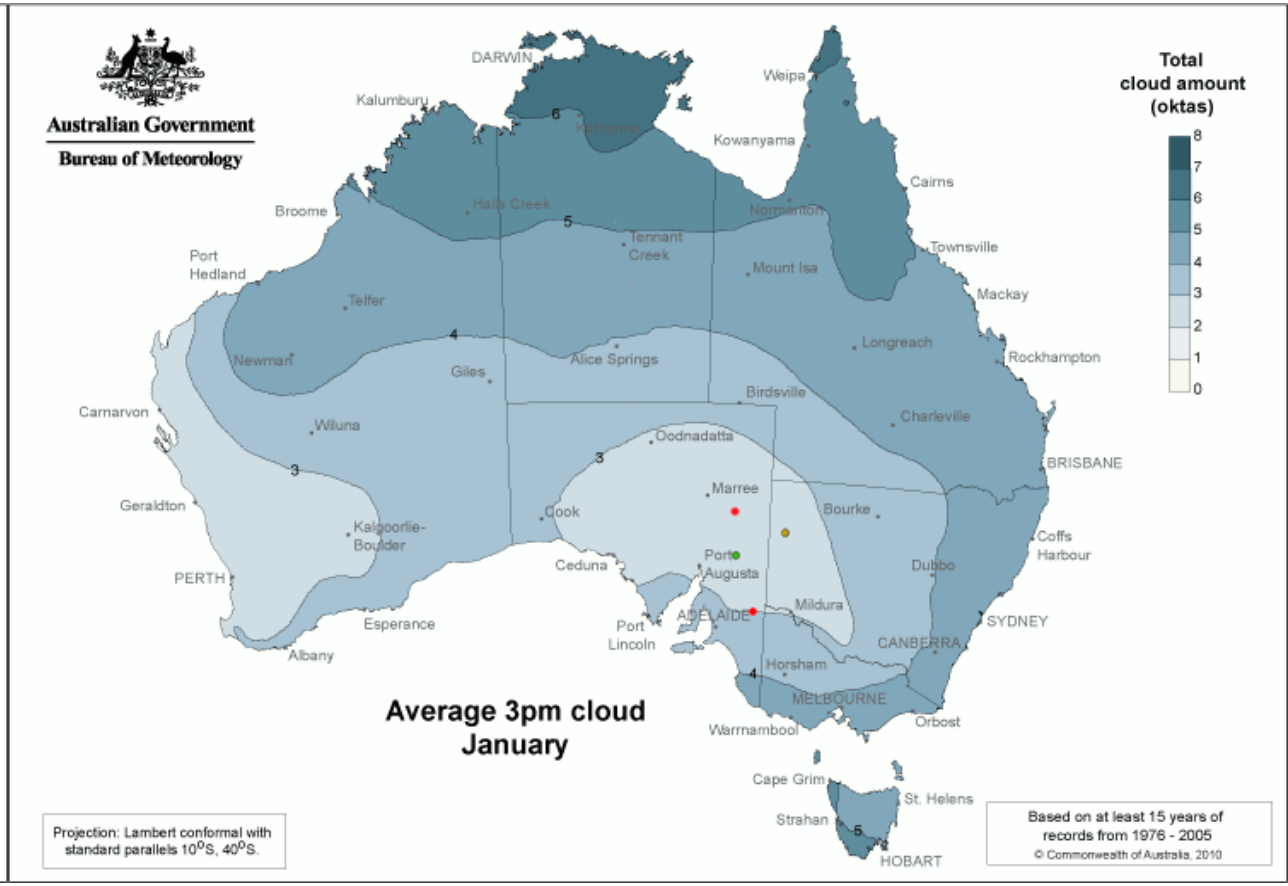
The northern wet/dry seasons are evident.

Good for NT and WA sites in winter(e.g. Milky Way).

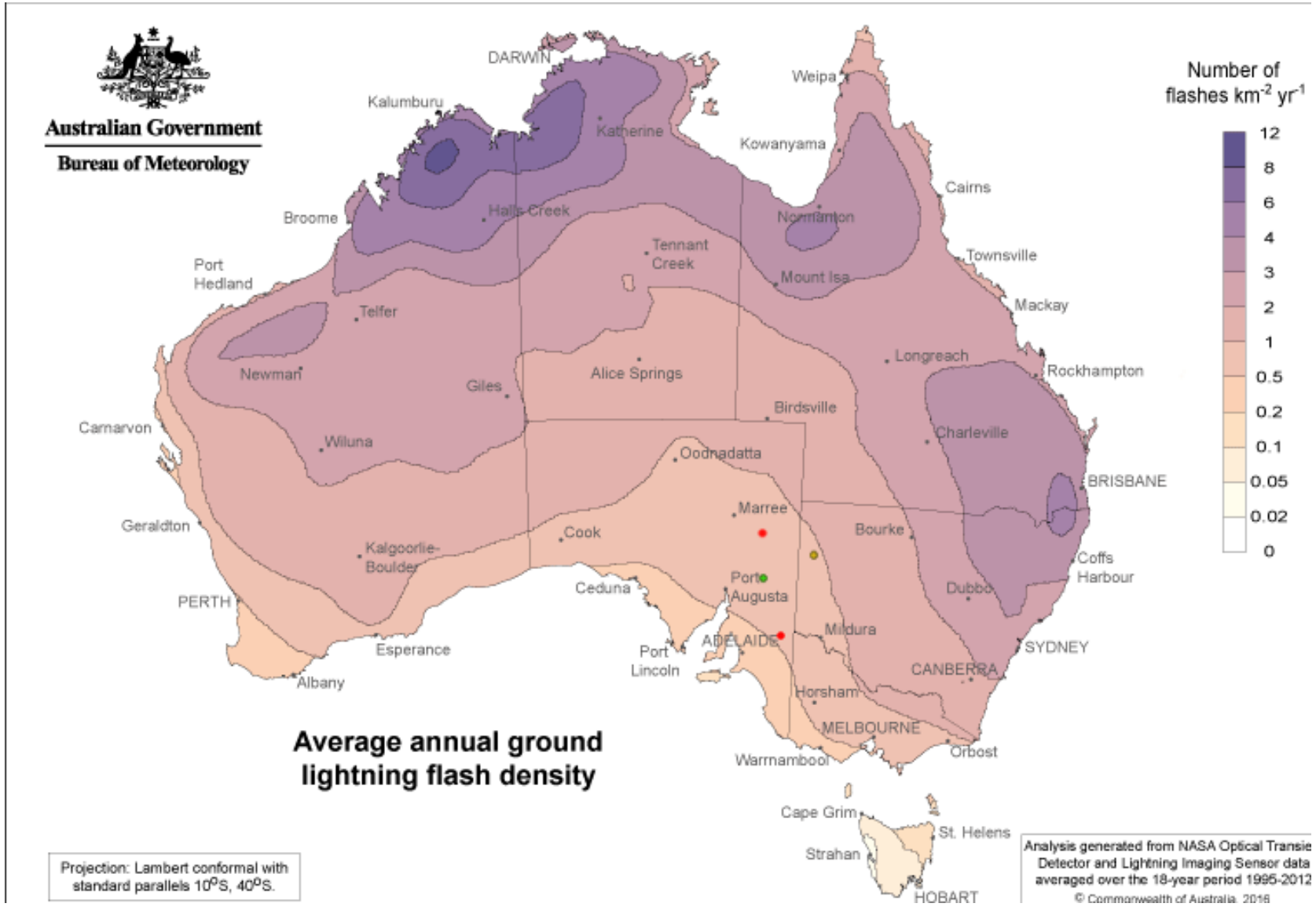
Siding Spring also drier in winter/spring than in summer/ autumn.



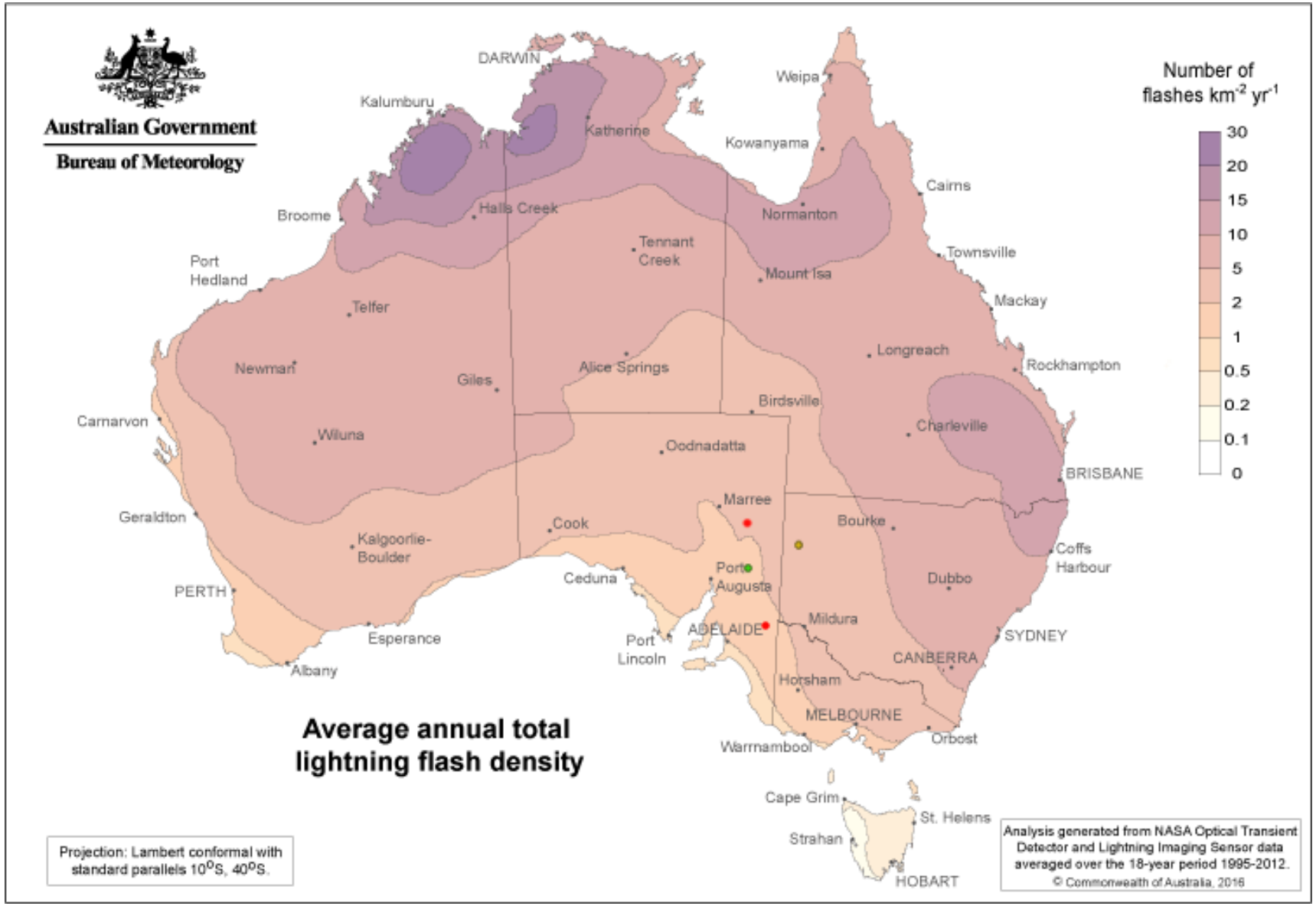

Australian Government
Bureau of Meteorology
Total cloud amount (oktas)
0
1
2
3
4
5
6
7
8
DARWIN
Kalumburu
Katherine
Weipa
Kowanyama
Cairns
Broome
Halls Creek
Normanton
Tennant Creek
Townsville
Port Hedland
Mount Isa
Telfer
Mackay
Newman
Giles
Alice Springs
Longreach
Rockhampton
Carnarvon
Birdsville
Wiluna
Charleville
Oodnadatta
BRISBANE
Marree
Geraldton
Bourke
Cook
Kalgoorlie-Boulder
Coffs Harbour
Port Augusta
PERTH
Ceduna
Dubbo
Mildura
Esperance
ADELAIDE
SYDNEY
Port Lincoln
CANBERRA
Albany
Horsham
MELBOURNE
Warrnambool
Orbost
Cape Grim
St. Helens
Strahan
HOBART
Average 9am cloud
January
Projection: Lambert conformal with standard parallels 10°S, 40°S.
Based on at least 15 years of records from 1976 - 2005
© Commonwealth of Australia, 2010


Australian Government
Bureau of Meteorology
Total cloud amount (oktas)
0
1
2
3
4
5
6
7
8
DARWIN
Kalumburu
Weipa
Kowanyama
Cairns
Broome
Halls Creek
Normanton
Tennant Creek
Townsville
Port Hedland
Mount Isa
Telfer
Mackay
Newman
Giles
Alice Springs
Longreach
Rockhampton
Carnarvon
Birdsville
Wiluna
Charleville
Oodnadatta
BRISBANE
Marree
Geraldton
Bourke
Cook
Kalgoorlie-Boulder
Coffs Harbour
Port Augusta
PERTH
Ceduna
Dubbo
Mildura
Esperance
ADELAIDE
SYDNEY
Port Lincoln
CANBERRA
Albany
Horsham
MELBOURNE
Warrnambool
Orbost
Cape Grim
St. Helens
Strahan
HOBART
Average 3pm cloud
January
Projection: Lambert conformal with standard parallels 10°S, 40°S.
Based on at least 15 years of records from 1976 - 2005
© Commonwealth of Australia, 2010

Greater likelihood of ground strikes in north-west WA (Hammersleys) and Siding Spring.



Southern interior sites have lower likelihood of ground strikes and other forms of lightning.

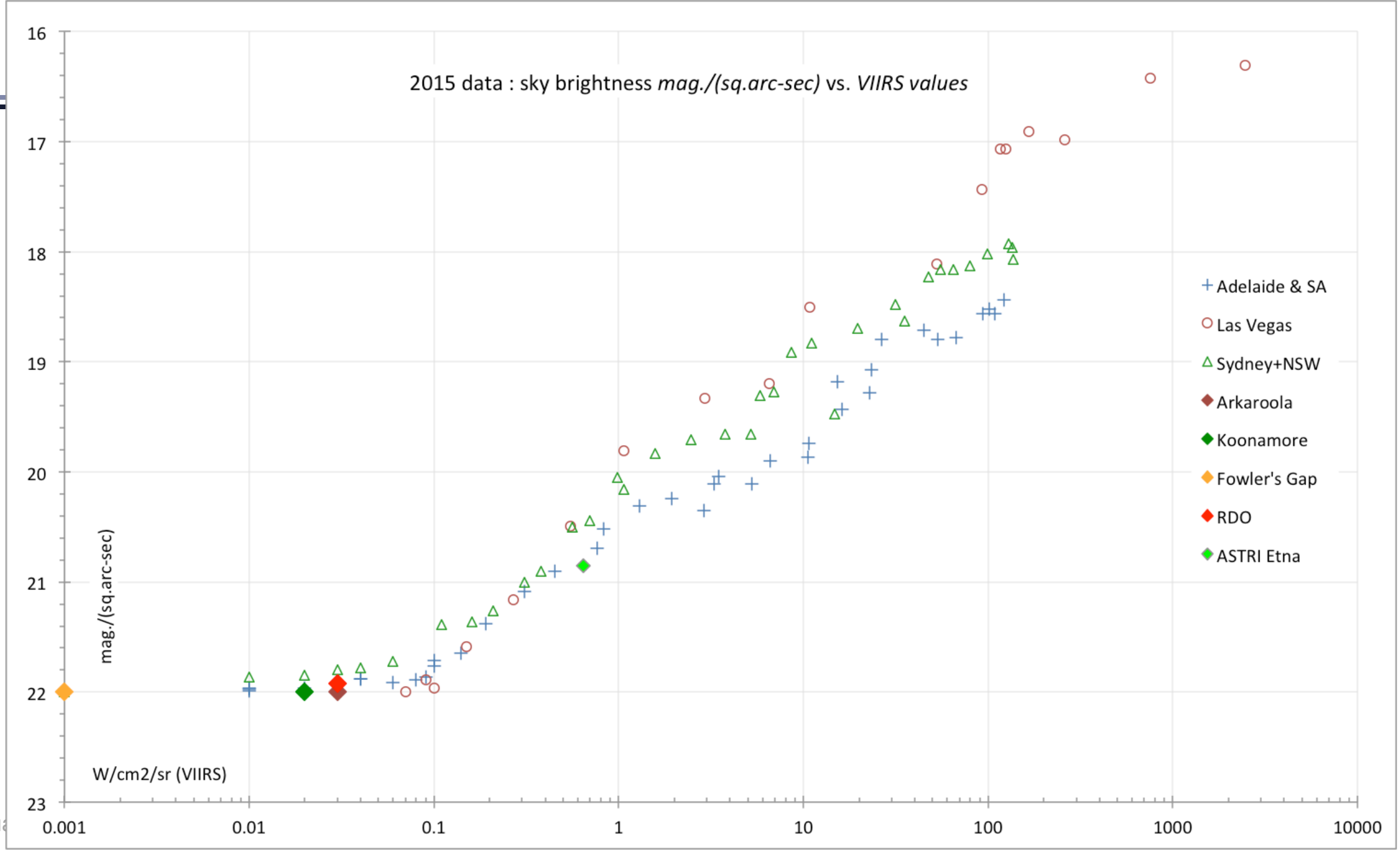


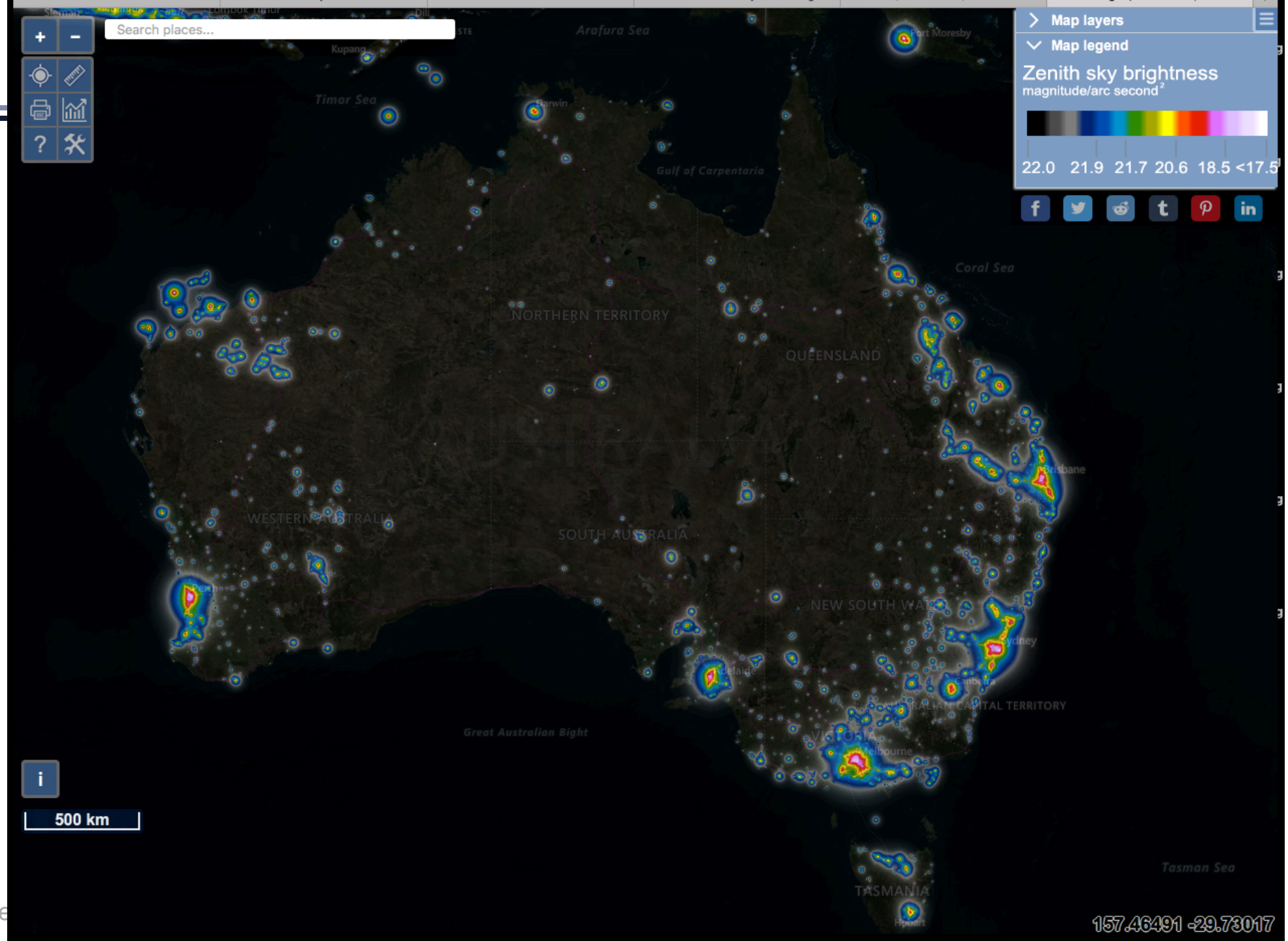
Night-sky brightness

- Unsurprisingly, sites with dark skies are preferred.
- Use maps of night-sky brightness (NSB) derived from satellite data to investigate this.

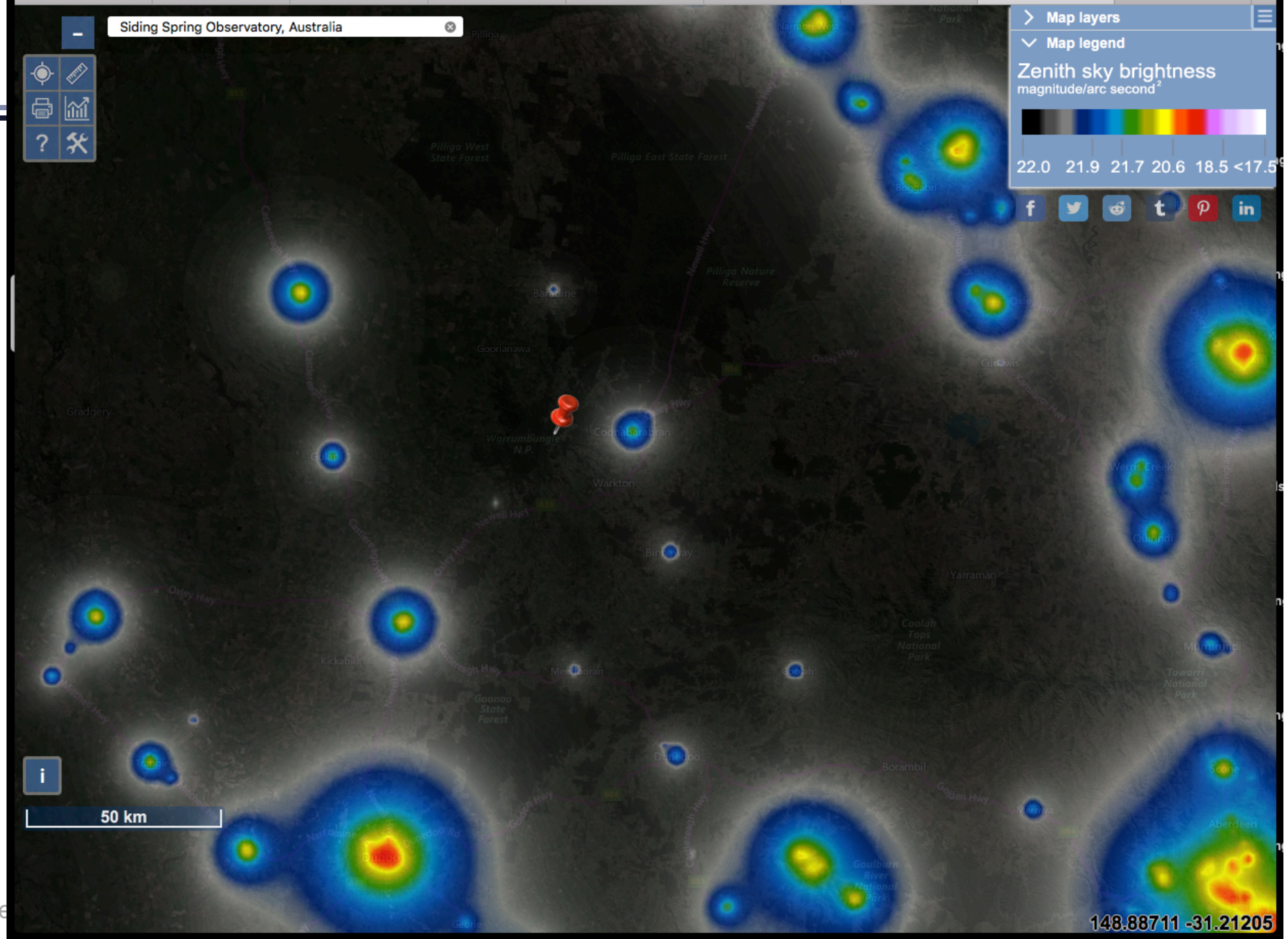
- https://www.lightpollutionmap.info

- Uses data from the VIIRS (Visible Infrared Imaging Radiometer Suite) on the Suomi National Polar-orbiting Partnership (NPP) satellite.
- Provides annual maps from 2012 onwards.
- 2015 data were used to model upward-looking NSB values in terms of familiar magnitude/square-arcsecond from the downward-looking VIIRS data to generate the “World Atlas 2015”.
- See https://advances.sciencemag.org/content/2/6/e1600377
- Caveats
  - light pollution usually increases with time, so 2015 values will be out of date- but are still generally instructive
  - changing spectra of light sources may mean more light outside of the VIIRS passband (~500-900nm), so over time may get false reductions in apparent light pollution with increasing use of LEDs, for example.

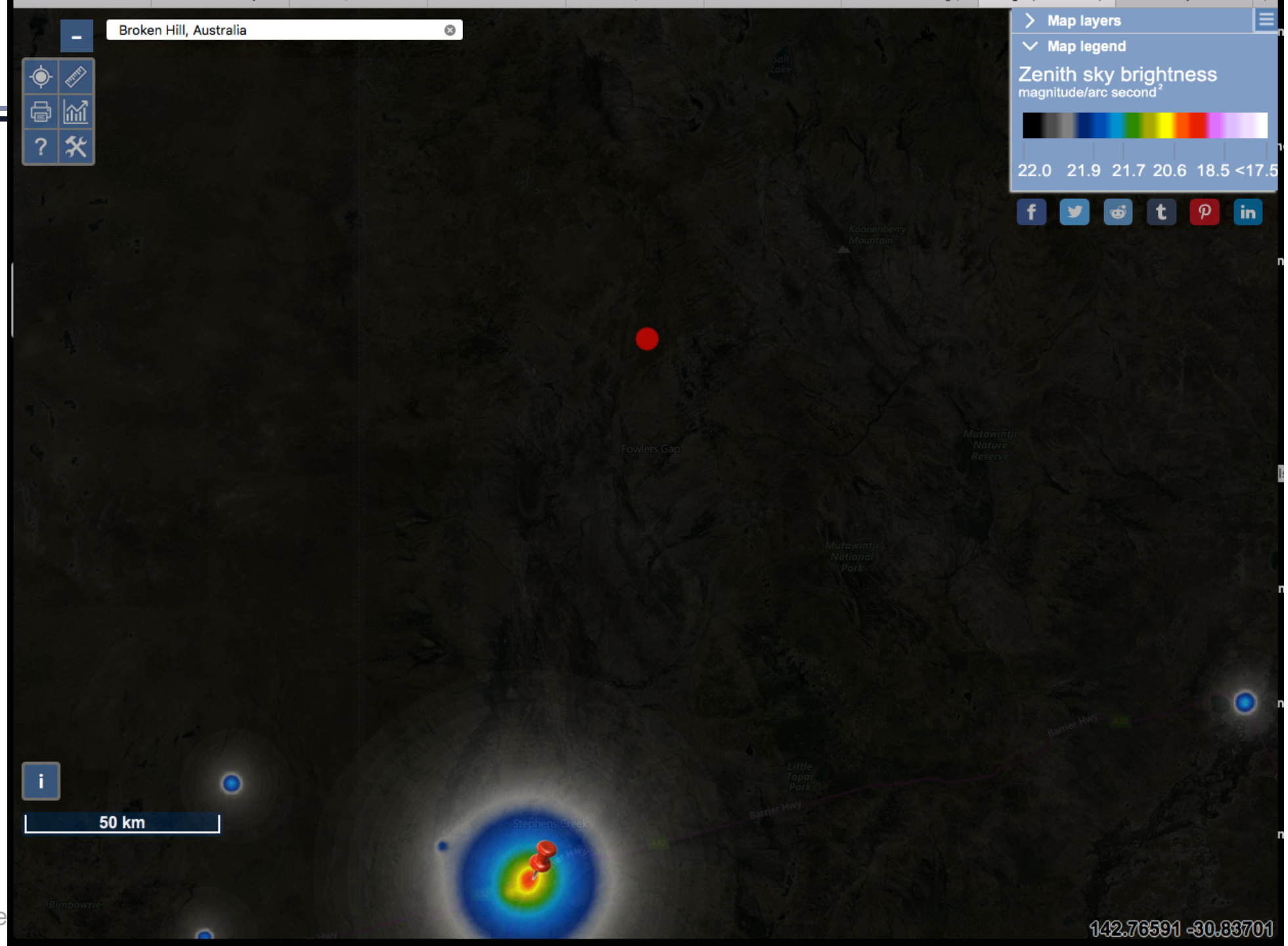

2015 data : sky brightness mag./(sq.arc-sec) vs. VIIRS values
mag./(sq.arc-sec)
W/cm2/sr (VIIRS)
16
17
18
19
20
21
22
23
0.001
0.01
0.1
1
10
100
1000
10000
Adelaide & SA
Las Vegas
Sydney+NSW
Arkaroola
Koonamore
Fowler's Gap
RDO
ASTRI Etna


Search places...
Map layers
Map legend
Zenith sky brightness
magnitude/arc second²
22.0 21.9 21.7 20.6 18.5 <17.5
Arafura Sea
Timor Sea
Gulf of Carpentaria
Coral Sea
NORTHERN TERRITORY
QUEENSLAND
WESTERN AUSTRALIA
SOUTH AUSTRALIA
NEW SOUTH WALES
Great Australian Bight
TASMANIA
Tasman Sea
Darwin
Brisbane
Sydney
Canberra
Melbourne
Adelaide
Perth
Hobart
Port Moresby
Kupang
500 km
157.46491 -29.73017

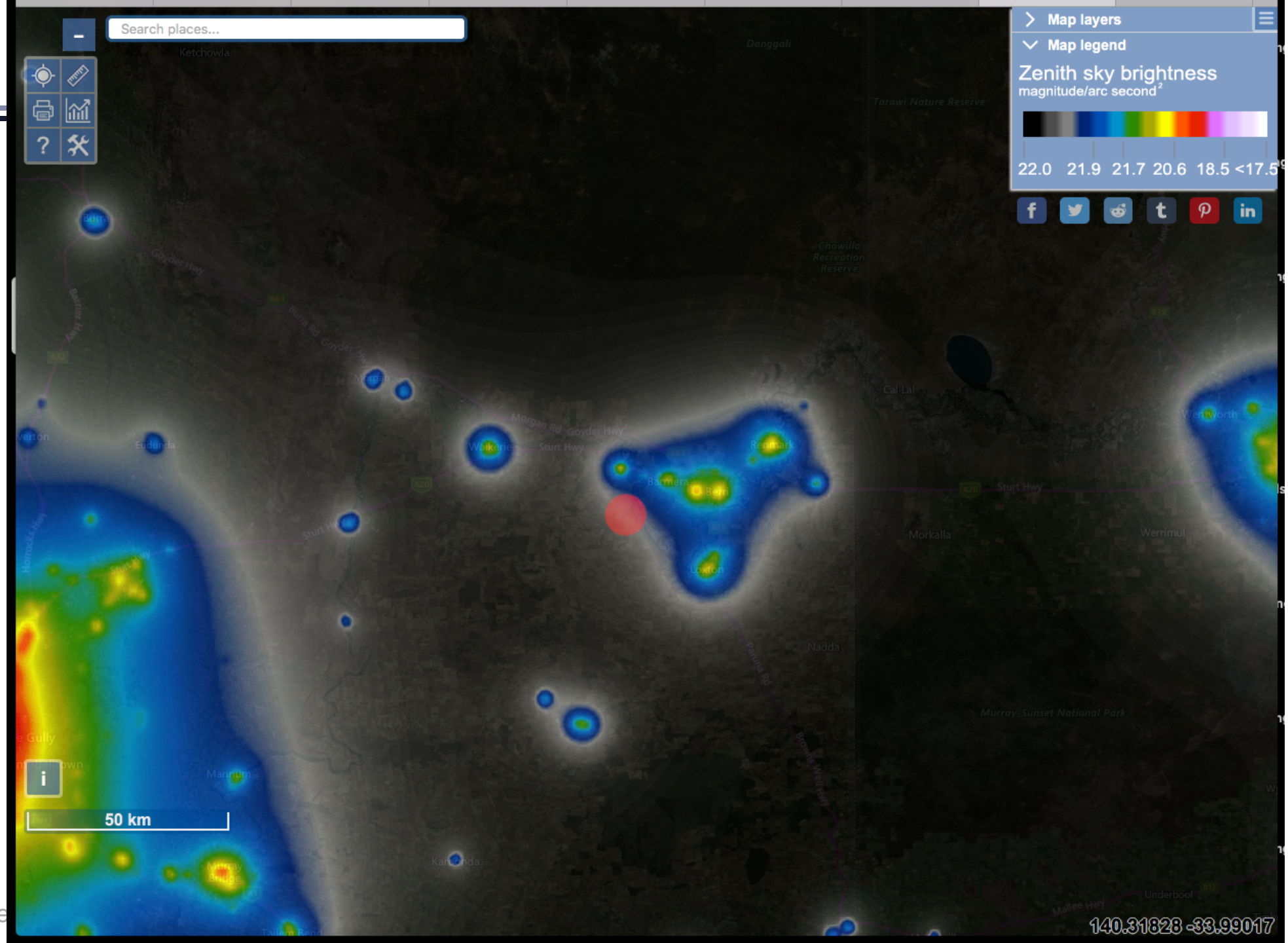
SSO
Mopra


Siding Spring Observatory, Australia
Map layers
Map legend
Zenith sky brightness
magnitude/arc second²
22.0 21.9 21.7 20.6 18.5 <17.5
50 km
148.88711 -31.21205

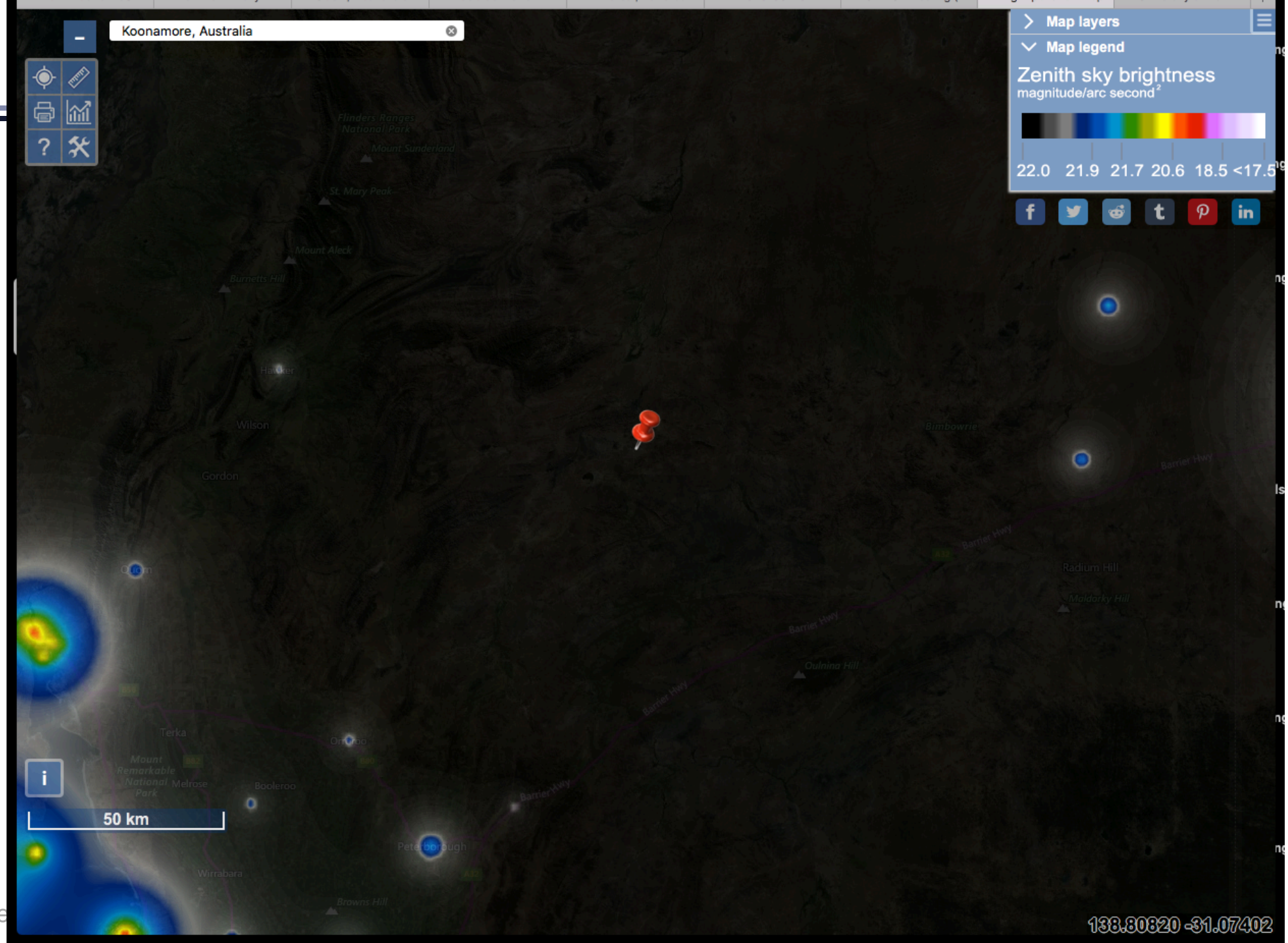
Fowler's Gap

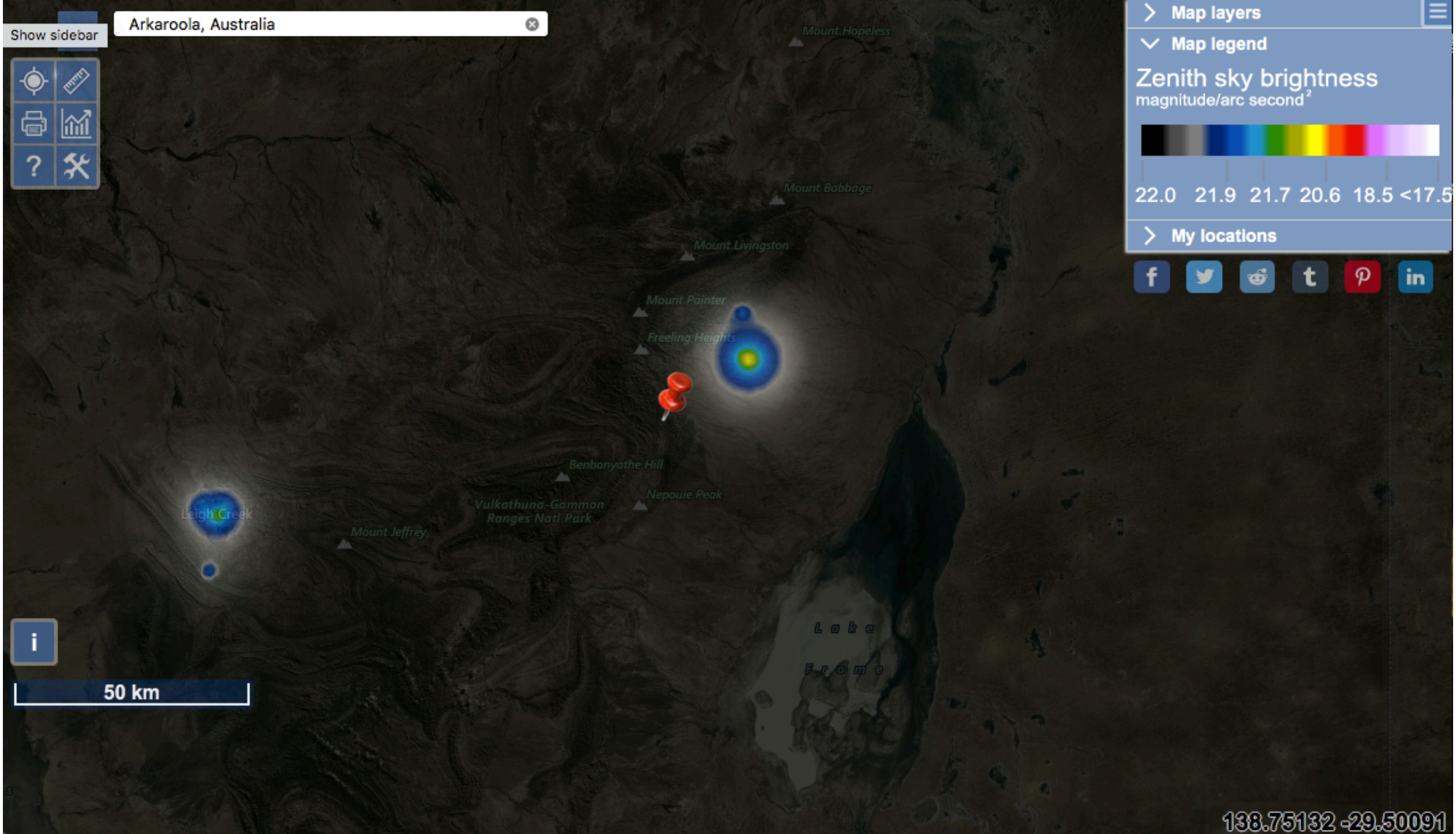

Broken Hill, Australia
Map layers
Map legend
Zenith sky brightness
magnitude/arc second²
22.0 21.9 21.7 20.6 18.5 <17.5
Fowlers Gap
Mutawintji Nature Reserve
Mutawintji National Park
Stephens Creek
Barrier Hwy
50 km
142.76591 -30.83701

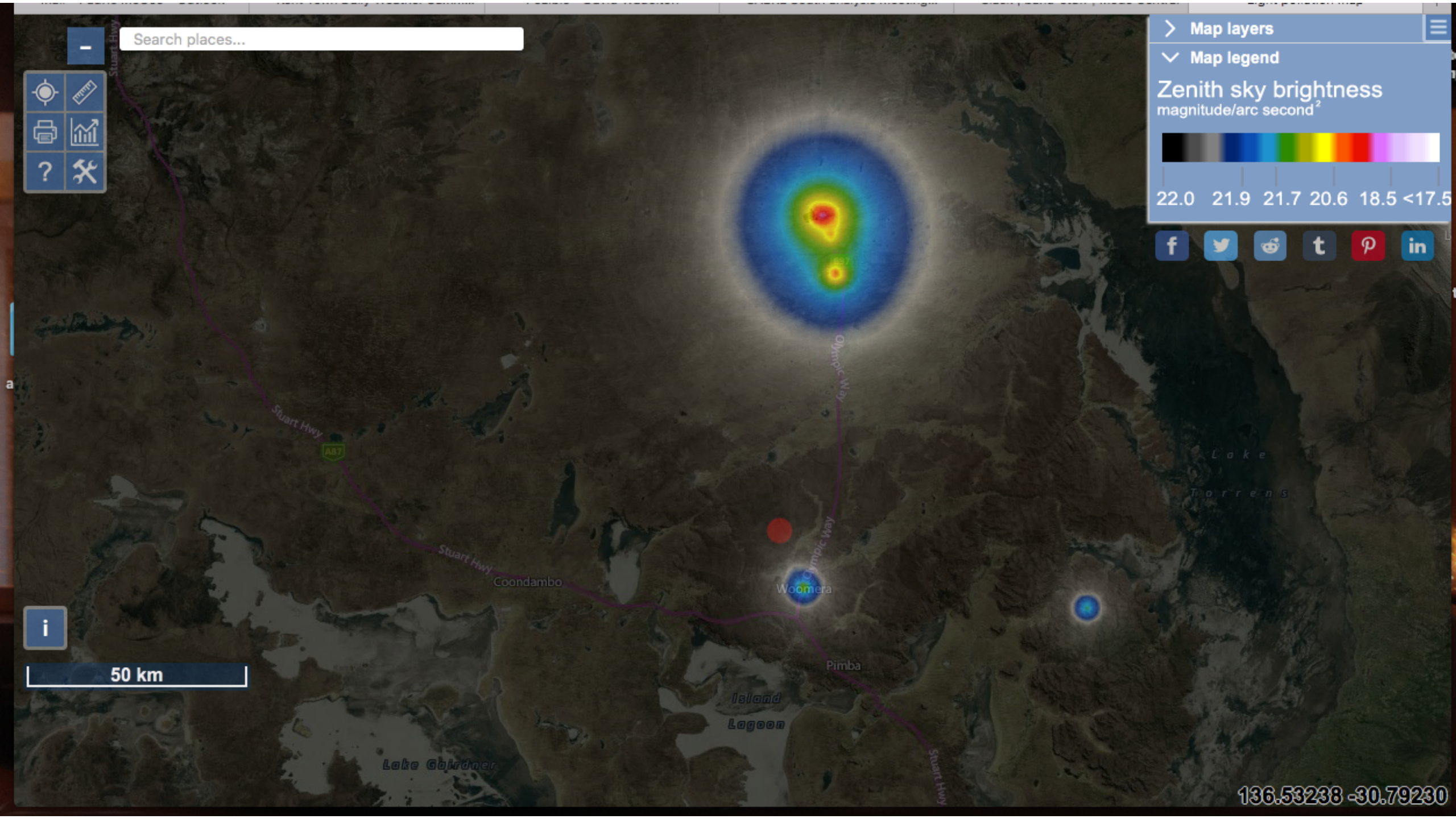
Moorook

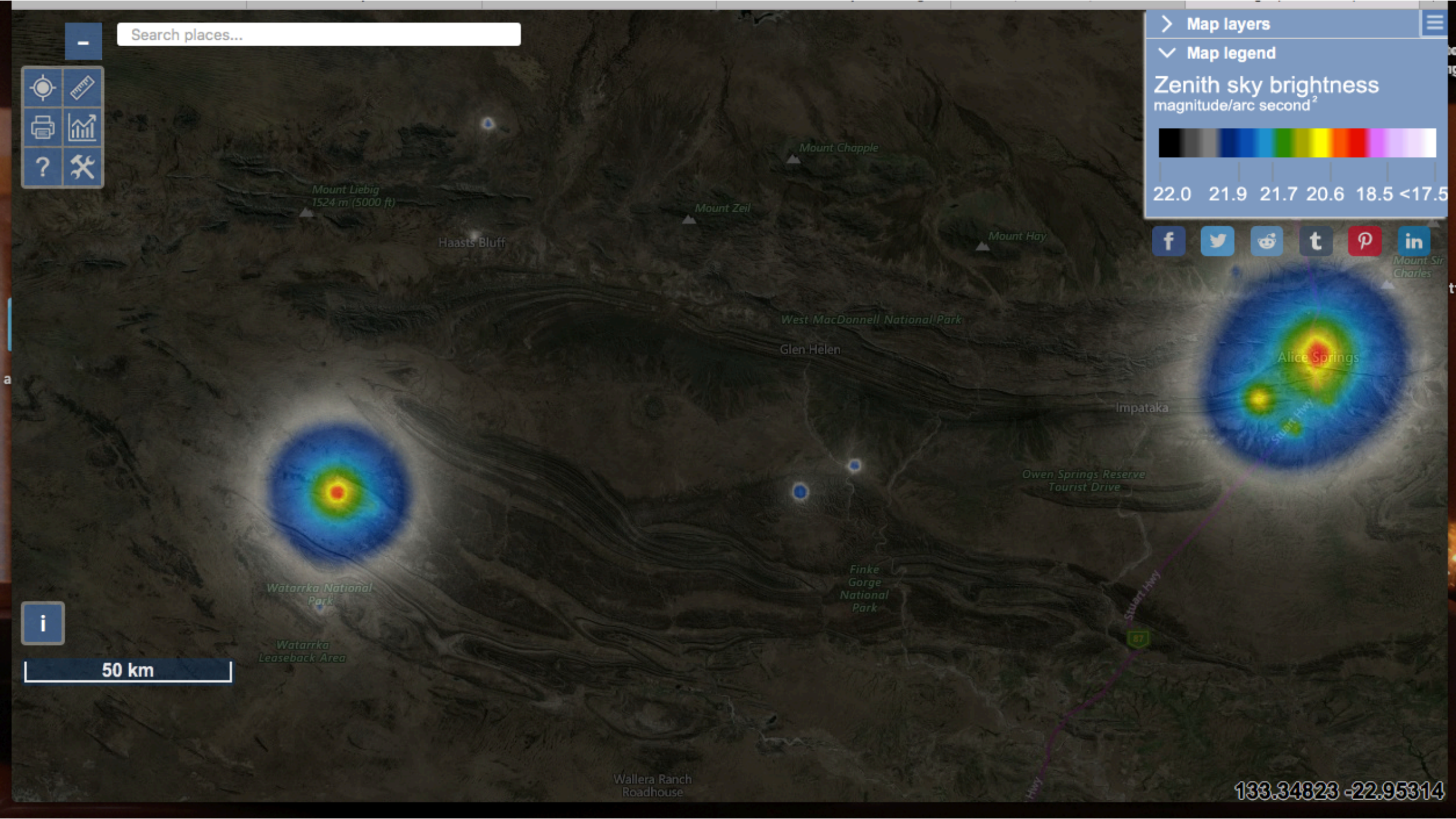

Search places...
Map layers
Map legend
Zenith sky brightness
magnitude/arc second²
22.0 21.9 21.7 20.6 18.5 <17.5
50 km
140.31828 -33.99017

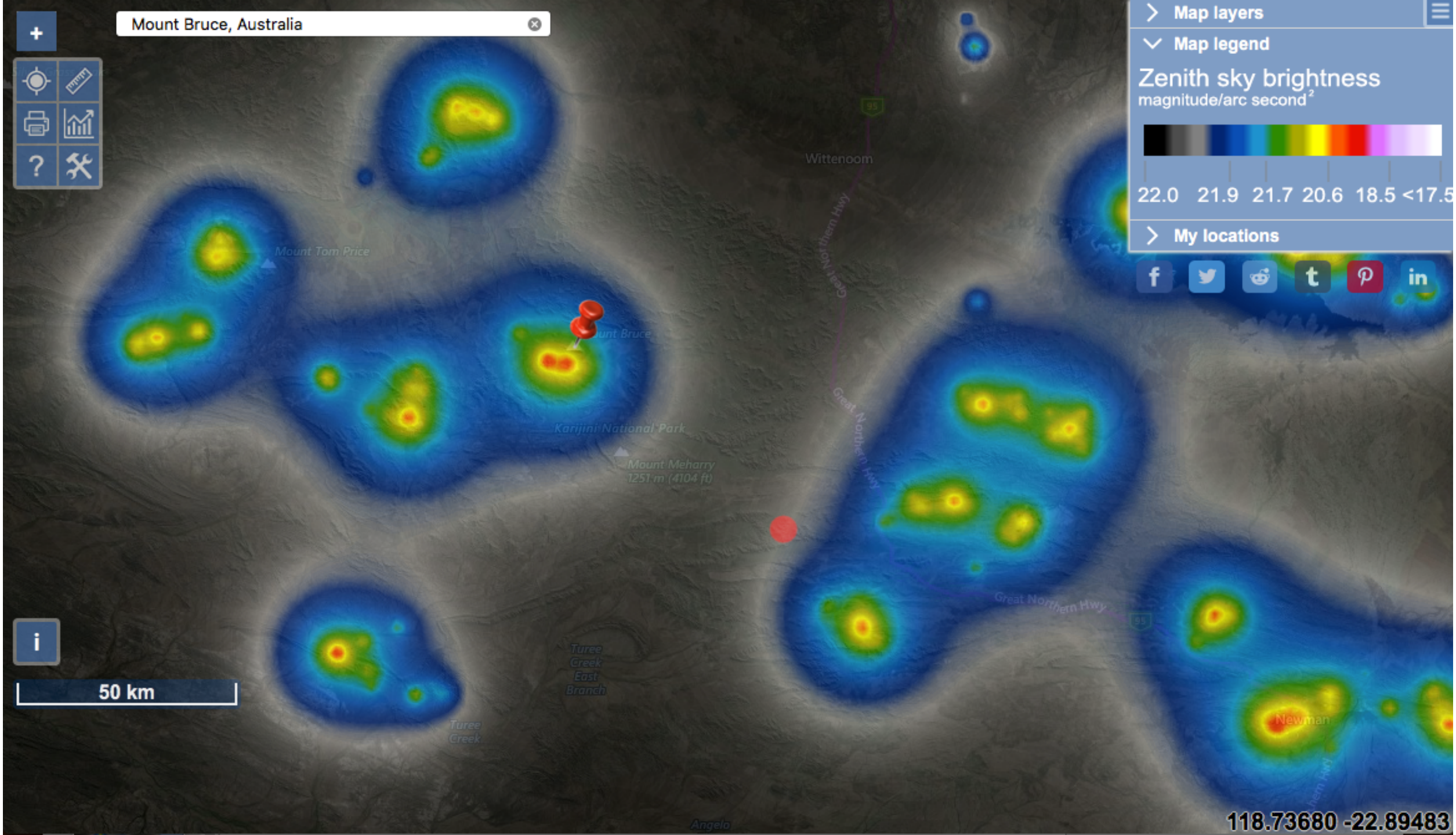
Koonamoore


Koonamore, Australia
Map layers
Map legend
Zenith sky brightness
magnitude/arc second²
22.0 21.9 21.7 20.6 18.5 <17.5
50 km
138.80820 -31.07402


Show sidebar
Arkaroola, Australia
Map layers
Map legend
Zenith sky brightness
magnitude/arc second²
22.0 21.9 21.7 20.6 18.5 <17.5
My locations
Mount Hopeless
Mount Babbage
Mount Livingston
Mount Painter
Freeling Heights
Benbonyathe Hill
Nepouie Peak
Vulkathuna-Gammon Ranges Natl Park
Leigh Creek
Mount Jeffrey
Lake Frome
50 km
138.75132 -29.50091


Search places...
Map layers
Map legend
Zenith sky brightness
magnitude/arc second²
22.0 21.9 21.7 20.6 18.5 <17.5
Stuart Hwy
A87
Olympic Way
Coondambo
Woomera
Pimba
Island Lagoon
Lake Gairdner
Lake Torrens
50 km
136.53238 -30.79230

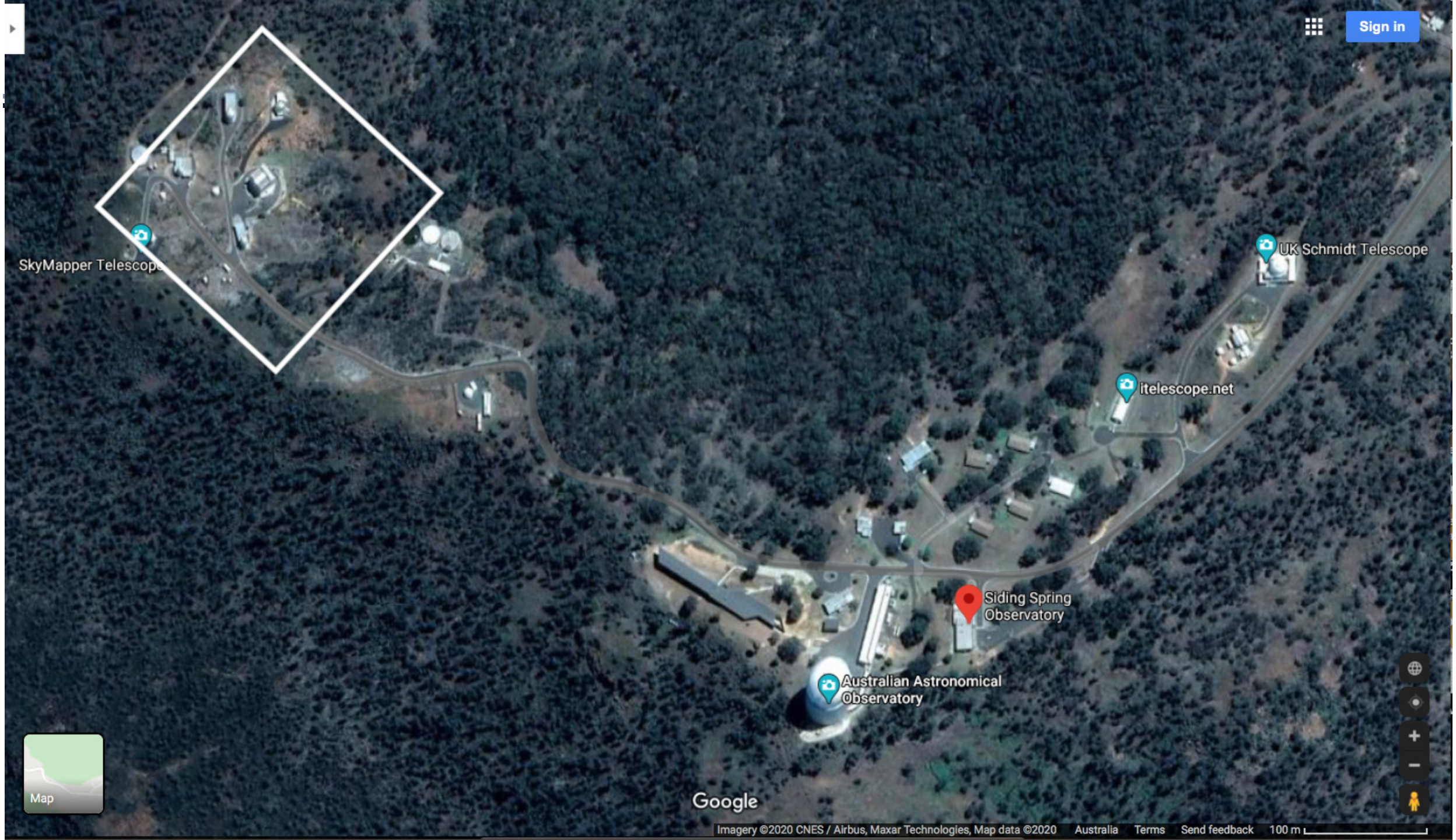

Search places...
Map layers
Map legend
Zenith sky brightness
magnitude/arc second²
22.0 21.9 21.7 20.6 18.5 <17.5
Mount Chapple
Mount Liebig
1524 m (5000 ft)
Mount Zeil
Haasts Bluff
Mount Hay
Mount Sir Charles
West MacDonnell National Park
Glen Helen
Alice Springs
Impataka
Stuart Hwy
Owen Springs Reserve
Tourist Drive
Finke Gorge National Park
Watarrka National Park
Watarrka Leaseback Area
Wallera Ranch Roadhouse
50 km
133.34823 -22.95314


Mount Bruce, Australia
Map layers
Map legend
Zenith sky brightness
magnitude/arc second²
22.0 21.9 21.7 20.6 18.5 <17.5
My locations
Wittenoom
Great Northern Hwy
Mount Tom Price
Karijini National Park
Mount Meharry
1251 m (4104 ft)
Turee Creek East Branch
Turee Creek
Angelo
Newman
50 km
118.73680 -22.89483

Site contours

- For elevated mountain sites such as SSO, the nature of the terrain is important.
- Array layout options
  - e.g. 5 scopes, square array with one central, edges ~ 200m length
  - e.g. 4 scopes, triangular array with one central, edges ~ 200m length
- The array would need to fit onto the terrain, which may mean some slight elevation difference between the elements.
- For a site such as SSO, need to consider the outline of the observatory boundary, as well as existing buildings and buried services.

- Next slide- just one example, a 200-metre square on the west ridge. Not the only possibility, but it does give an idea of the scale


Sign in
SkyMapper Telescope
UK Schmidt Telescope
itelescope.net
Siding Spring Observatory
Australian Astronomical Observatory
Map
Google
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Australia
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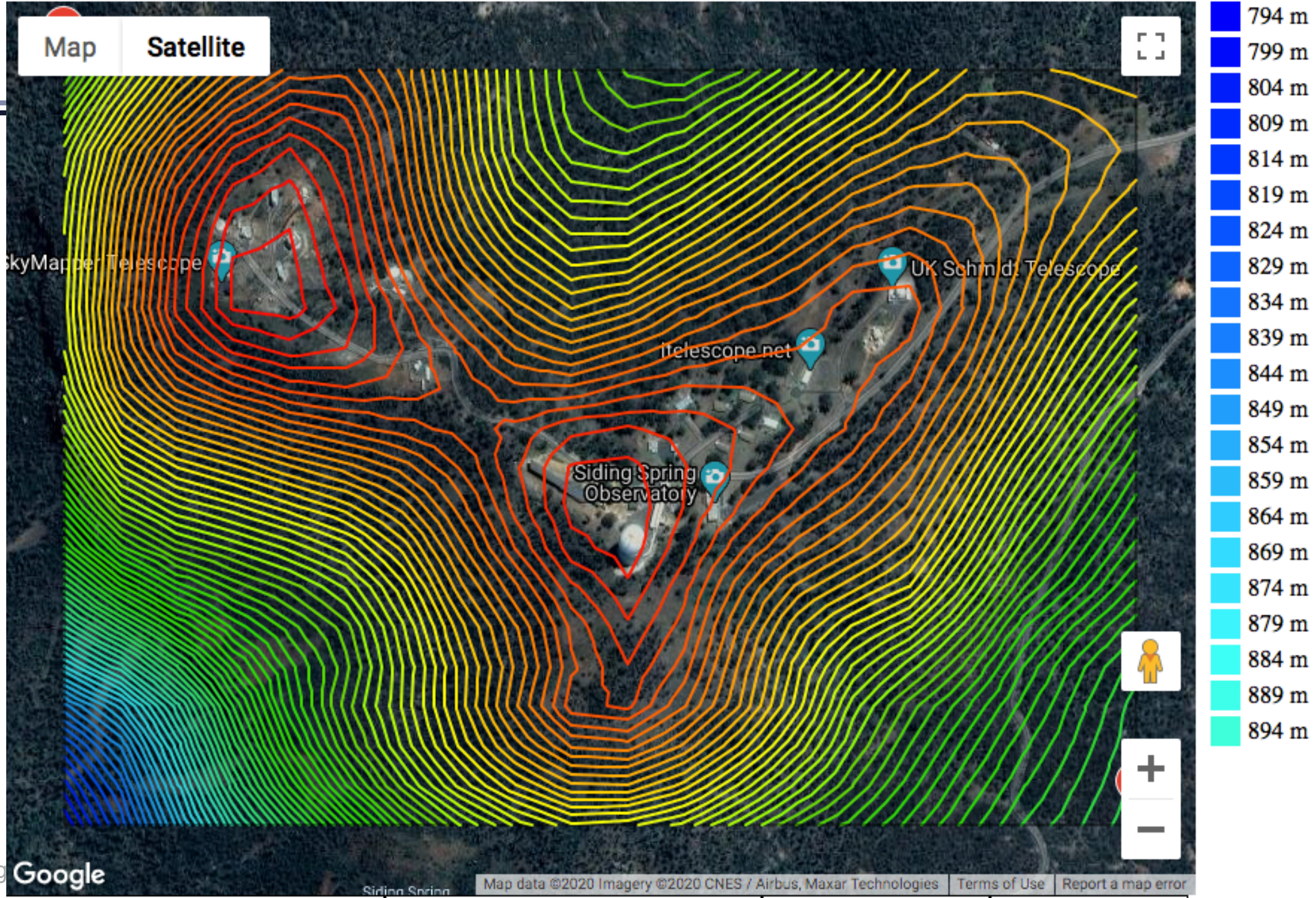
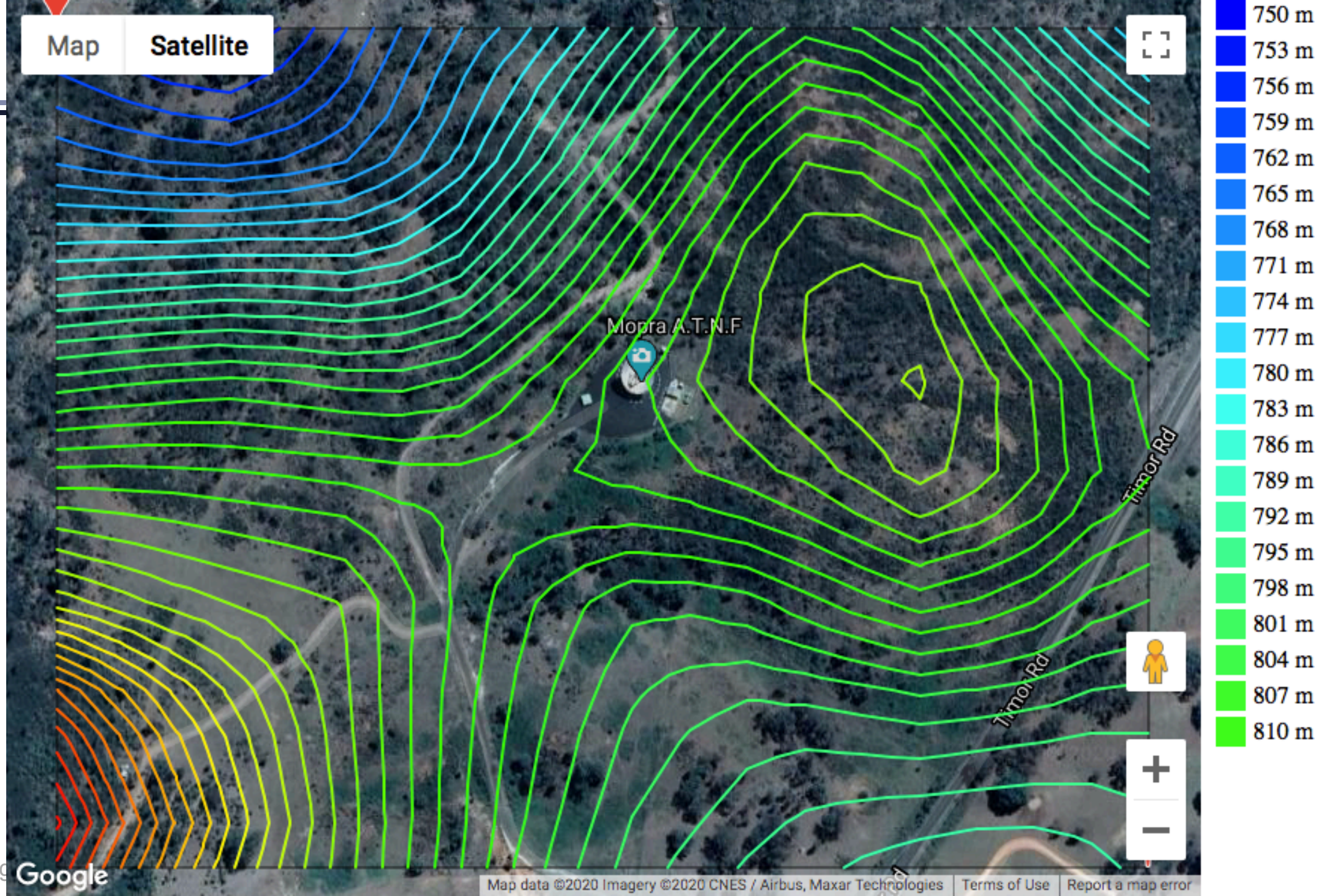
100 m

- The site https://contourmapcreator.urgr8.ch can produce basic contour maps from Google Earth data.
- Useful for getting some idea of the terrain for a particular location (some sites, e.g. SSO, also have higher-quality contour maps as part of their documentation).

SSO 5m-interval



Mopra 3m-interval



Summary

- Several potential sites have been selected for reviewing weather and other factors for the site of a small IACT array.
- Historical BoM data can be used to produce maps showing some relevant factors.
- BoM provides some iso maps for relevant factors.
- Experimenting with using MODIS data to produce night-time cloud maps.
- NSB maps show all sites to be quite dark, but some have nearby sources of light which may evolve over the lifetime of the array.
- Contour maps can be used to look at the local terrain for possible sites, since we have an array of scopes, not just a single instrument (also, simulations will help determine if a high-elevation or low-elevation site is preferred- see Simon's work).

- Further work
  - Extract and analyse further weather data, such as severe weather situations
  - MODIS
    - Investigate cirrus analysis
    - Analyse daytime data such as optical thickness
    - Analyse other data products such as the aerosol product
- Drafting of a corresponding paper is in progress…
- See if estimates of changes due to climate change are available.