Quantifying Potential New Sites for IACTs in Australia

Cross Checks with Data
from Siding Spring Observatory

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Siding Spring Observatory (SSO)

- Located on Mount Woorut (~1160 m)

- 27 km west of Coonabarabran, NSW

- Record of weather data
  (courtesy of James Cameron, ANU)

  - 2011 - 2020: Temperatures, humidity,
    rainfall, dew point, pressure, brightness, sky
    meter temperature
    (every 10 minutes)

  - 2018: All Sky Camera Images
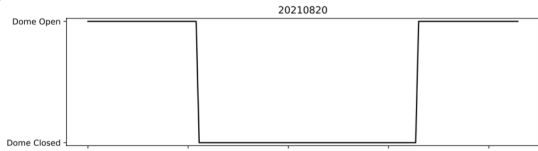   (every 0.5 minutes)
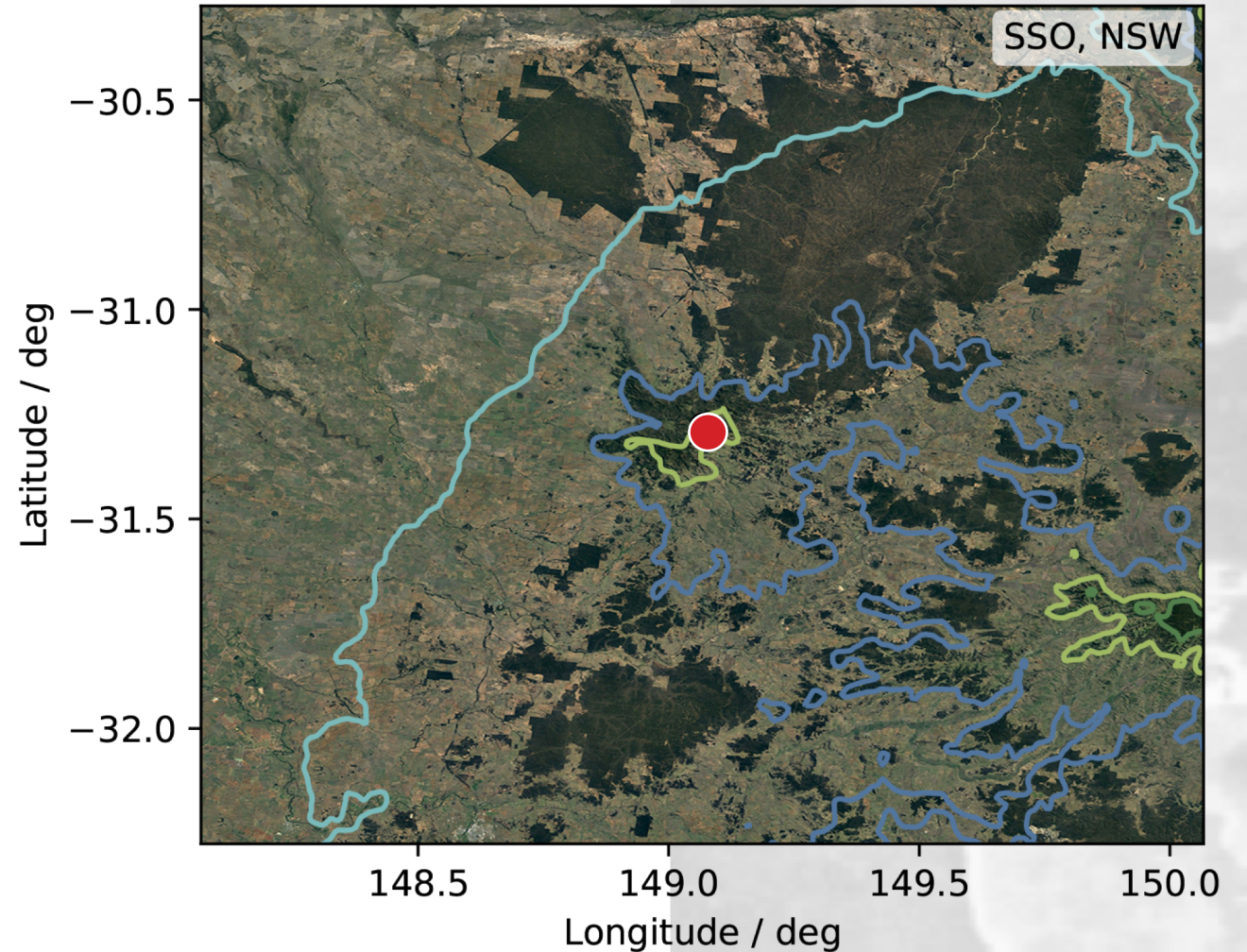
SSO: Nightly Weather Data (selection)

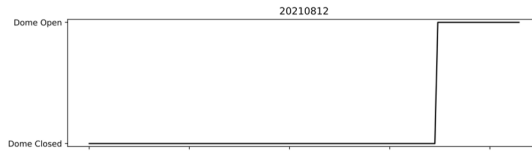clear or mostly clear, no rain

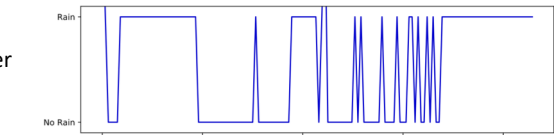intermittent clear, with some rain

mostly cloudy, frequent rain

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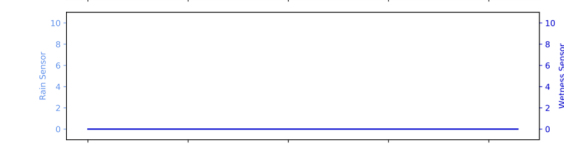
dome
rain (weather station)
rain /wetness sensor Boltwood
humidity %
sky temp. ° C
brightness (arbitrary)
outside temp. ° C
ave. & max. wind (kph)
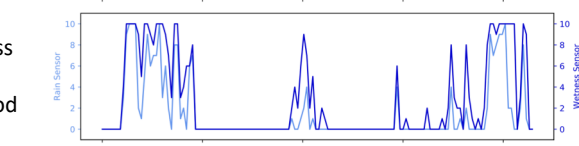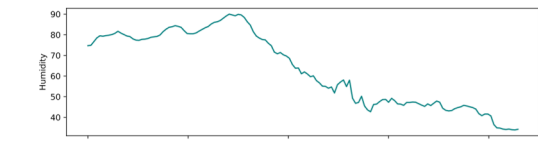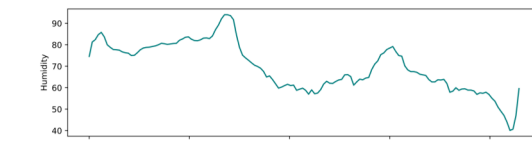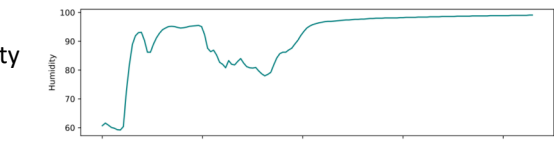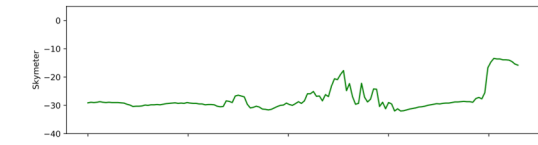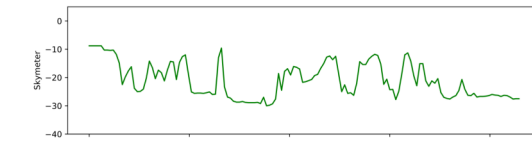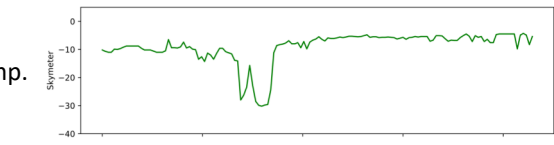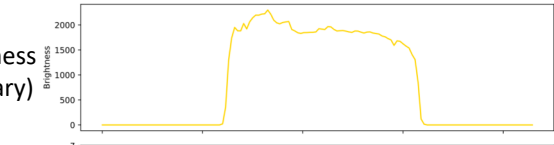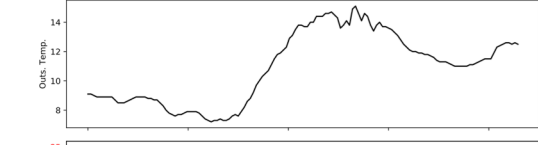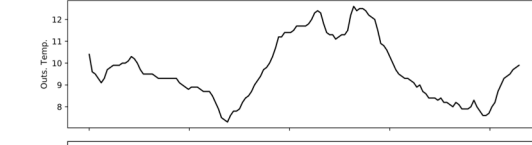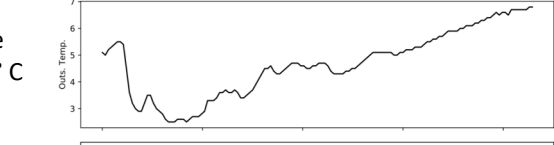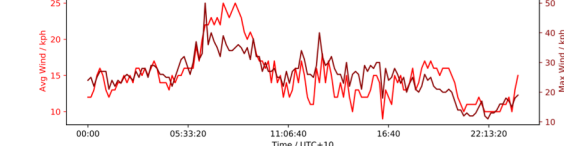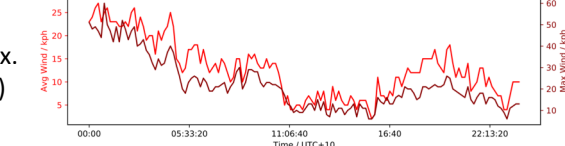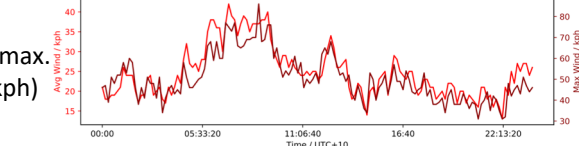
SSO: Wind

CTA requirements

- Survival wind gusts:
  Damage beyond Serviceability Limit State must not occur due to wind gusts of up to 170 km/h

- Survival wind speed:
  Damage beyond Serviceability Limit State must not occur due to 10 minute average wind speeds of up to 100 km/h

(Serviceability Limit State: Damage can be repaired in-situ using available spare parts and a normal level of on-site manpower.)

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Maximum wind gust: 229 km/h
(Wind gusts > 170 km/h occurred on 2 nights in 10 years)

Wind Gust Speed / (km/h)

Maximum wind speed: 137 km/h
(Wind speeds > 100 km/h occurred on 5 nights in 10 years)

Wind Speed / (km/h)
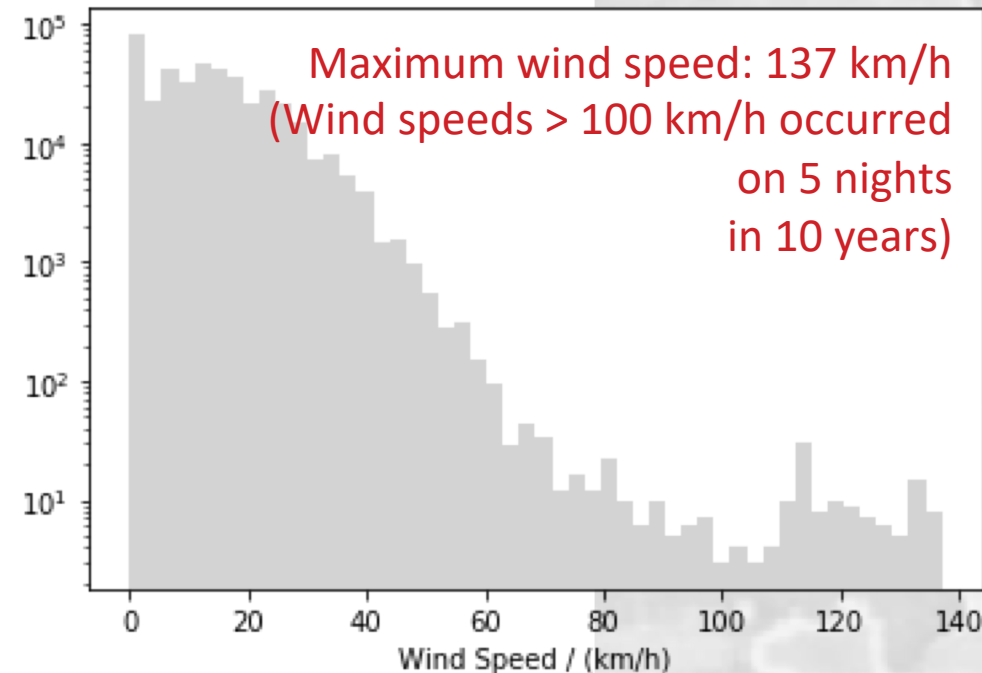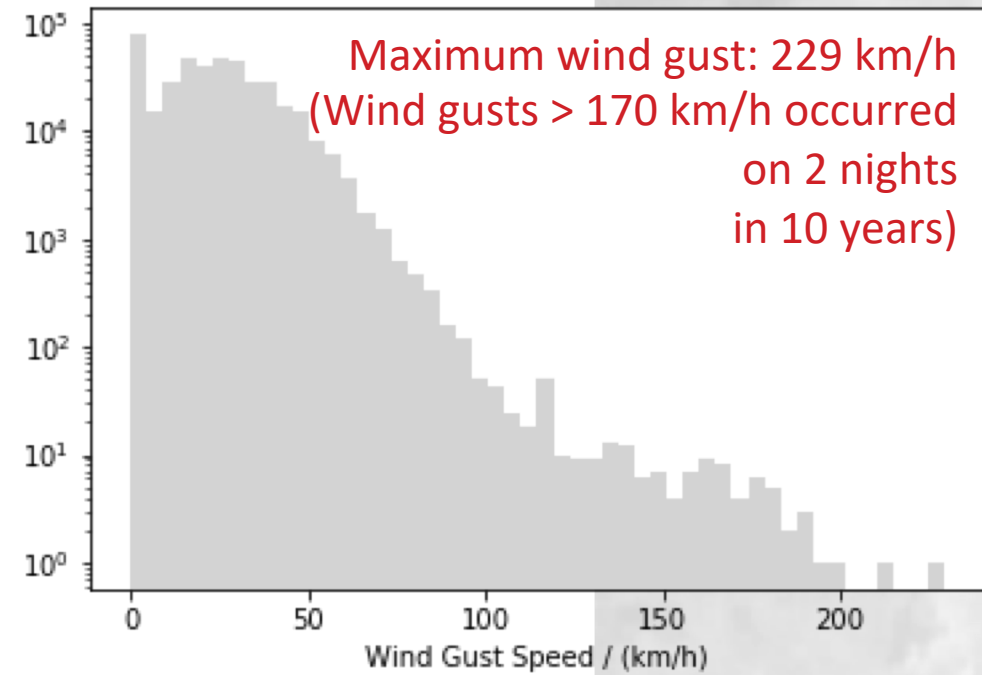
SSO: Rain

monthly average of % of time during the night when rainfall was recorded (for 2018)

96% of night time is dry
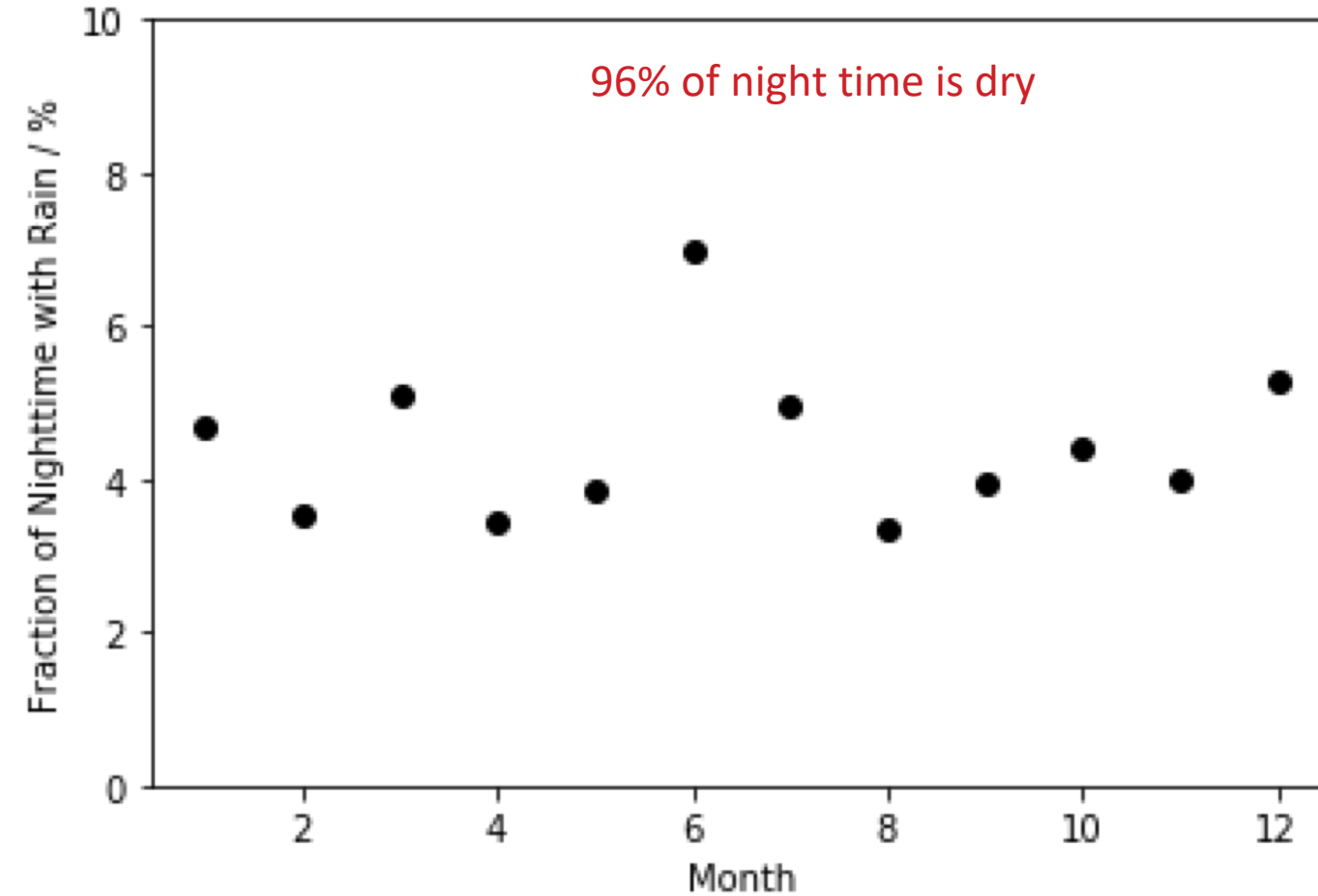
SSO: Clouds

- Boltwood passive IR cloud monitor (single-channel, pointed slightly off zenith)
  - 8-14 microns
  - temperature difference relative to the ground temperature
  - approx. +-40 degree angle of main sensitivity
- clear sky cooler than cloudy sky
- also has rain/wetness sensor, brightness meter
- nominal value sky temperature < -25° C taken to indicate clear skies
  - manual notes that these limits should be checked/set for each site
- slightly inclined from zenith to allow water run-off (manual says 10 degrees)
- don't know in which direction it points
- also data from a Unihedron Sky Quality Meter (sky brightness in mag./sq. arc-second)

- **the main interest is to get a ground-based cross-check of downward-looking MODIS-based cloudiness estimates**
  - ***how reliably can MODIS-only measurements be used to characterised site cloudiness?***

SSO: Clouds (based on Boltwood sky temperatures)

OUR Definition of Cloud Flags

- Very cloudy (= 0): > -10 °C

- Probably cloudy (= 1): > -25 °C & > -10 °C

- Probably clear (= 2): < -25 °C & > -30 °C

- Clear (= 3): < -30 °C

- generally rains when skies are warmer, i.e. cloudy

- but tails to each distribution
  - variability in nightly conditions
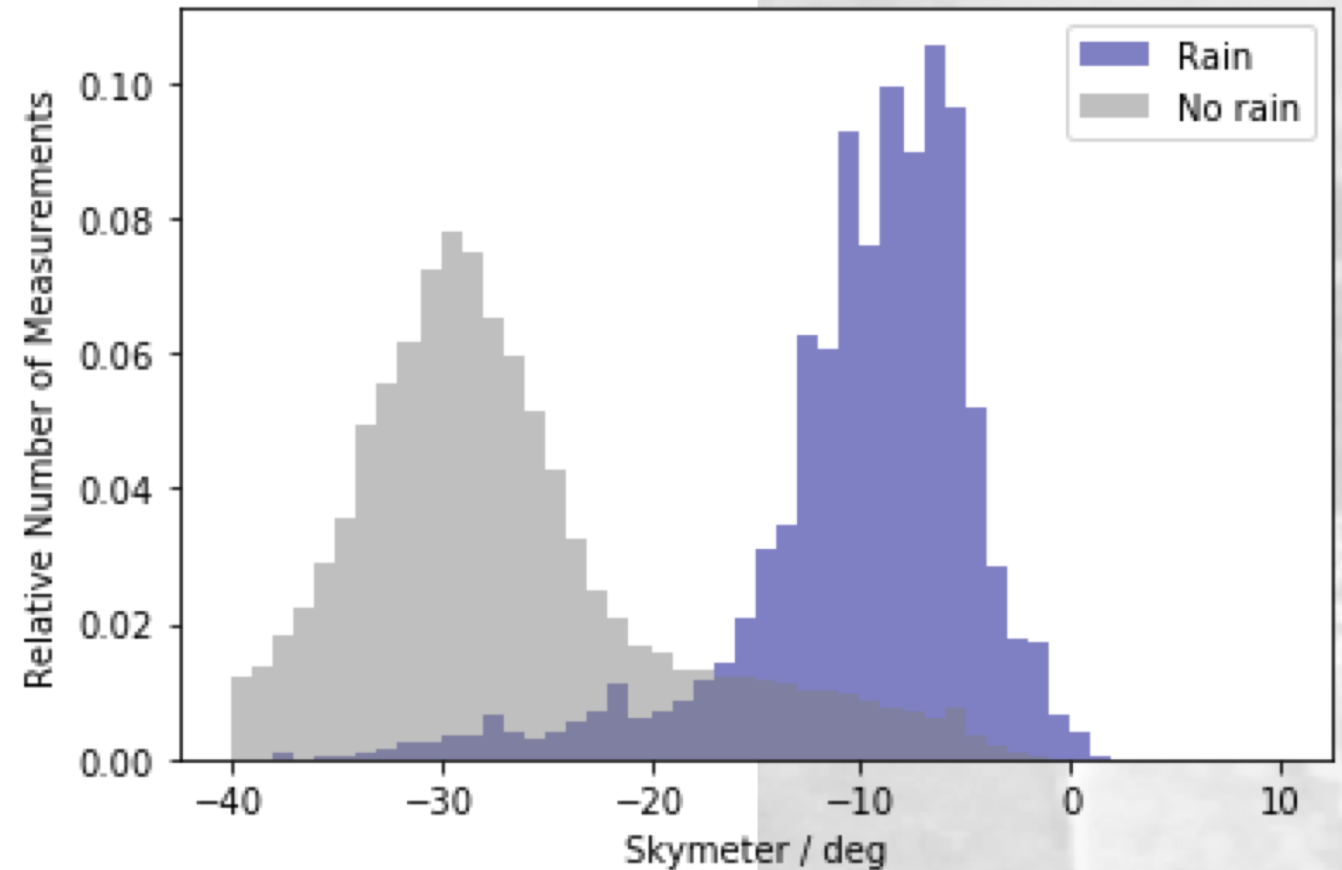
MODIS: Clouds

MODIS data can be used to generate maps of its supplied cloud masks, i.e. maps of cloudiness over an area

- a MODIS pixel is 1 km-square

Definition of Cloud Flags (Masks)

- Very cloudy: 0

- Probably cloudy: 1

- Probably clear: 2

- Clear: 3
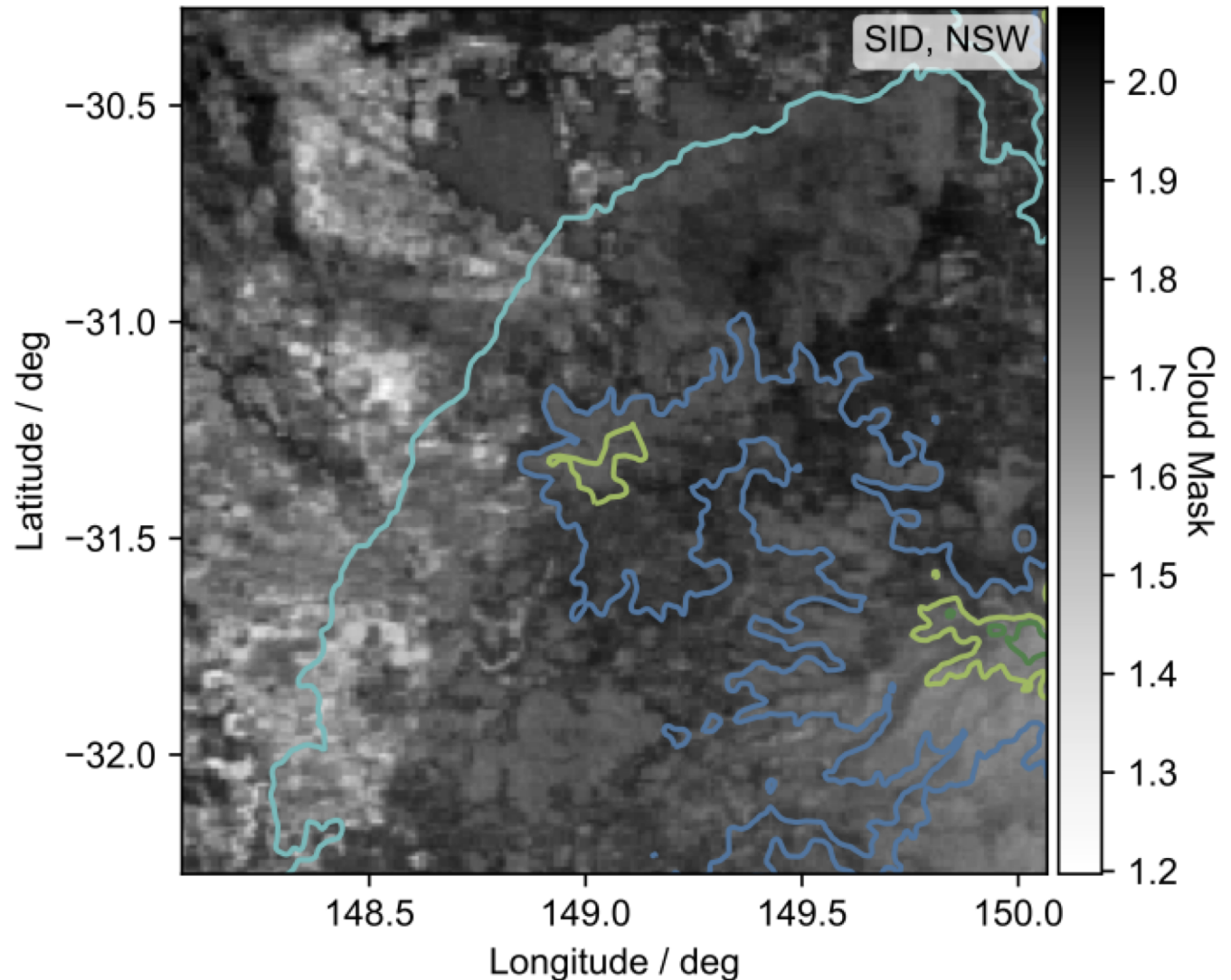
Comparison: MODIS - SSO

(Comparison performed for 2018 : at times of
MODIS passes)
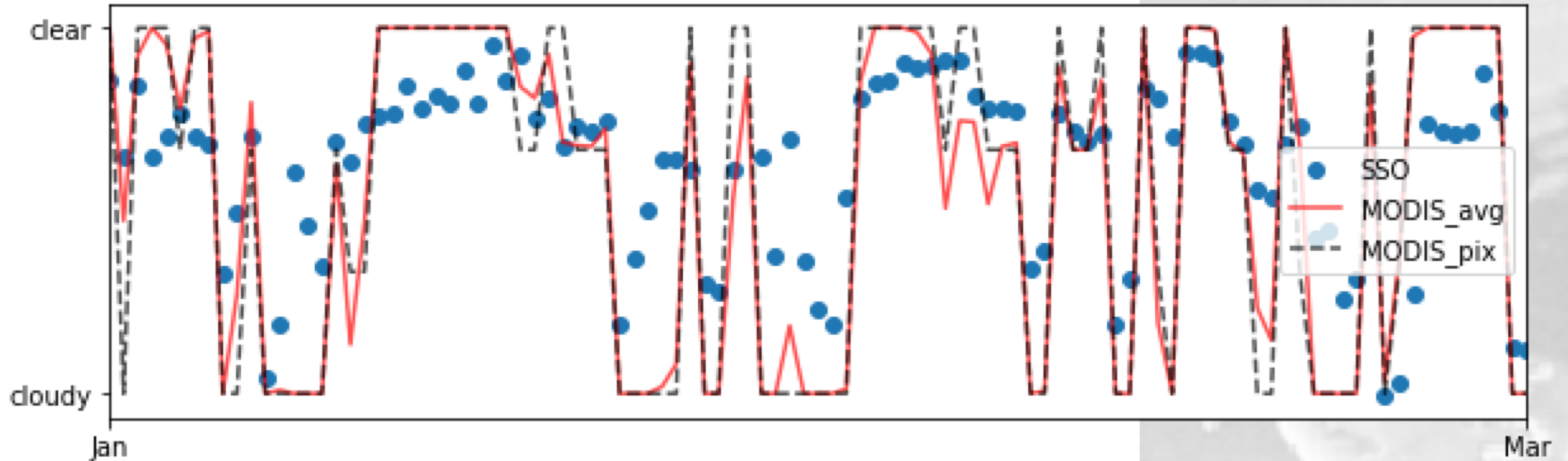
- MODIS cloud masks: "_avg" = average over 10km-radius circle; "_pix" = single MODIS pixel
- perfect agreement = dots follow the lines
- most discrepancies = SSO less cloud indicated (by sky temps) than MODIS indicates

Comparison: MODIS - SSO

- good agreement under clear conditions (also high proportion of clear nights)

- also agreement for very cloudy conditions

- but quite a few "MODIS cloudy" matched by "SSO probably clear"...

(Comparison performed for 2018)

# of MODIS passes in 2018

Comparison: MODIS - SSO

# of MODIS passes
in 2018
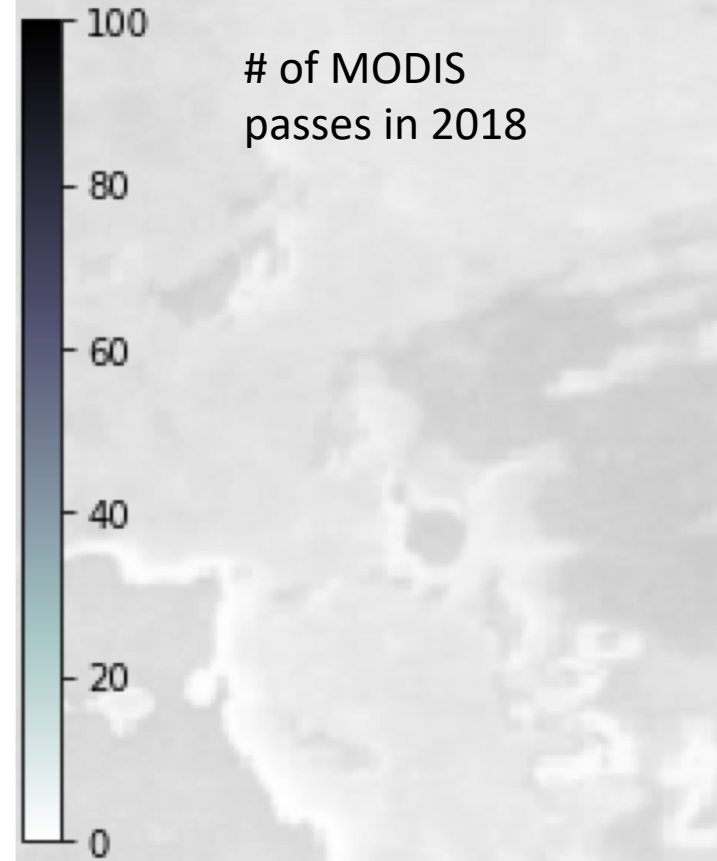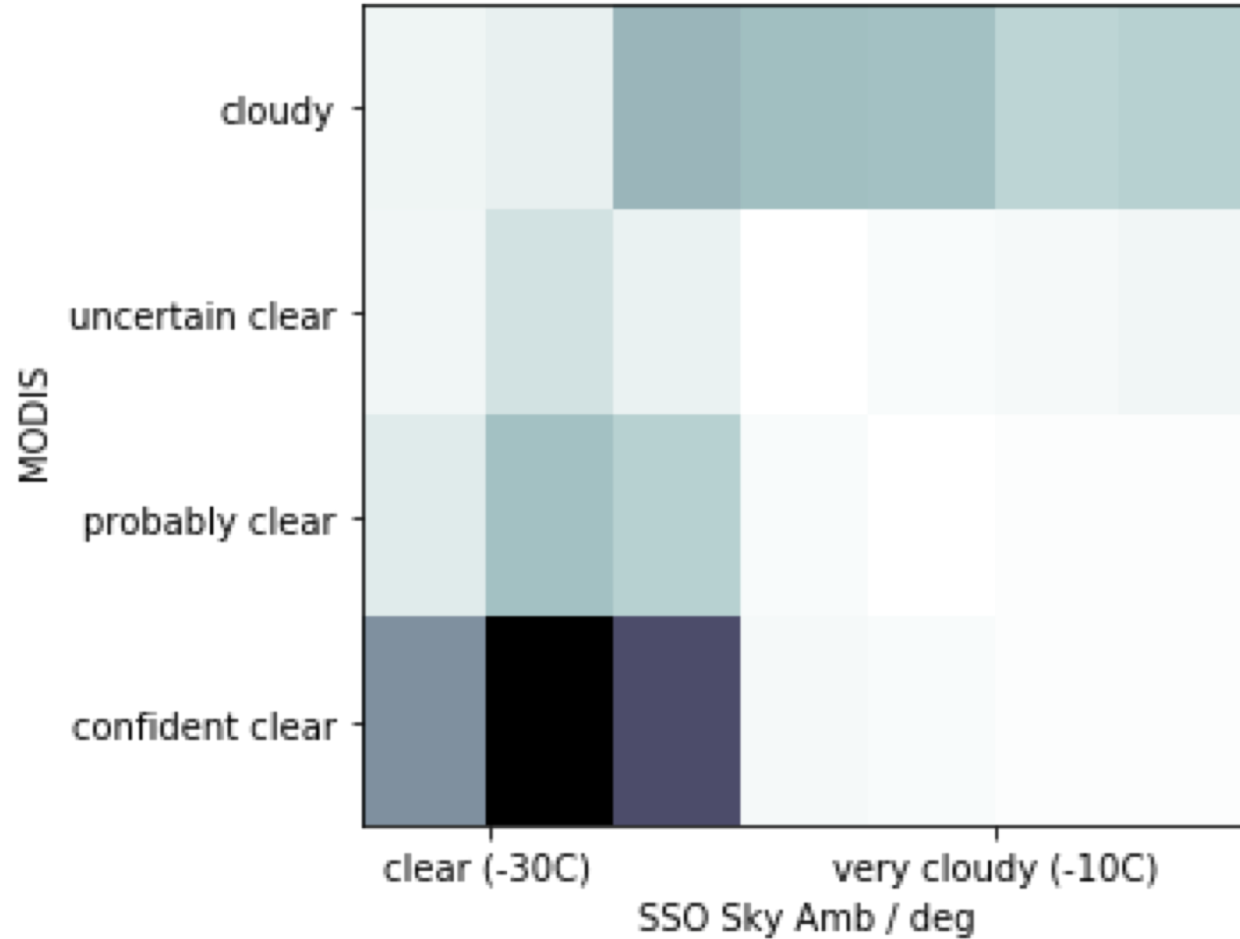
(Comparison performed for 2018)

Comparison: MODIS - SSO

sso_UTC+10	sso_cloudflag	modis_cmask_1	modis_height
2018-10-14 01:10:00	3.0	0.0	1750.0
2018-10-15 23:20:00	3.0	0.0	9200.0
2018-10-16 00:50:00	3.0	0.0	11750.0
2018-10-26 01:30:00	3.0	1.0	2250.0
2018-10-28 22:50:00	3.0	2.0	-999.0
2018-11-03 22:10:00	3.0	0.0	12200.0
2018-11-04 01:20:00	3.0	0.0	10200.0
2018-11-04 23:00:00	3.0	1.0	2250.0
2018-11-12 22:10:00	3.0	0.0	2800.0
2018-11-12 23:40:00	3.0	1.0	1750.0
2018-11-24 22:30:00	3.0	0.0	16300.0
2018-11-27 01:30:00	3.0	1.0	1900.0
2018-11-27 23:00:00	3.0	1.0	1900.0
2018-12-03 22:20:00	3.0	0.0	9500.0
2018-12-04 01:40:00	3.0	0.0	3050.0
2018-12-05 22:10:00	3.0	1.0	2050.0
2018-12-21 22:10:00	3.0	1.0	2750.0

SSO sky temp (sso_cloudflag) says "clear", but MODIS single-pixel cloud mask says "cloudy"

Quantifying Australian

Comparison: MODIS - SSO

2016-12-03 22:23:23

AAT

SSO: Cirrus visible in ASC images (but sky temp says clear)
MODIS: High clouds
—> All good
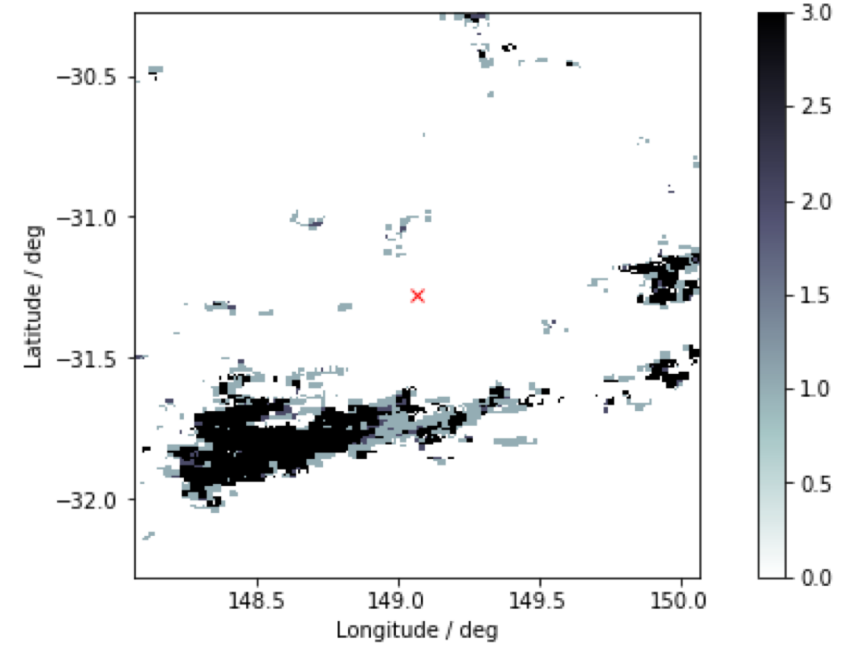
- white = MODIS cloudy
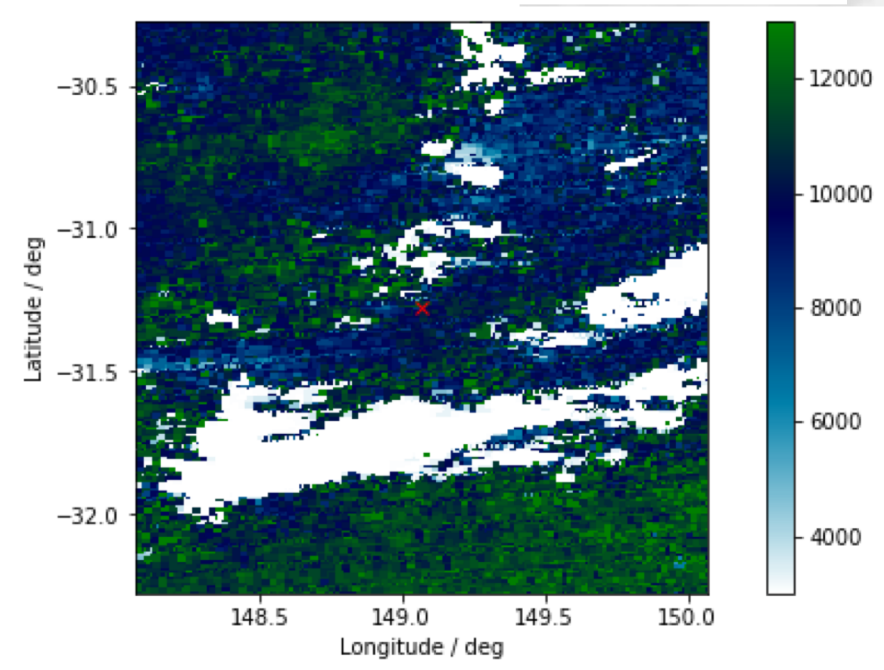
- but is high-level cloud, ~9,000m +

Comparison: MODIS - SSO

2018-10-28 22:52:28

AAT
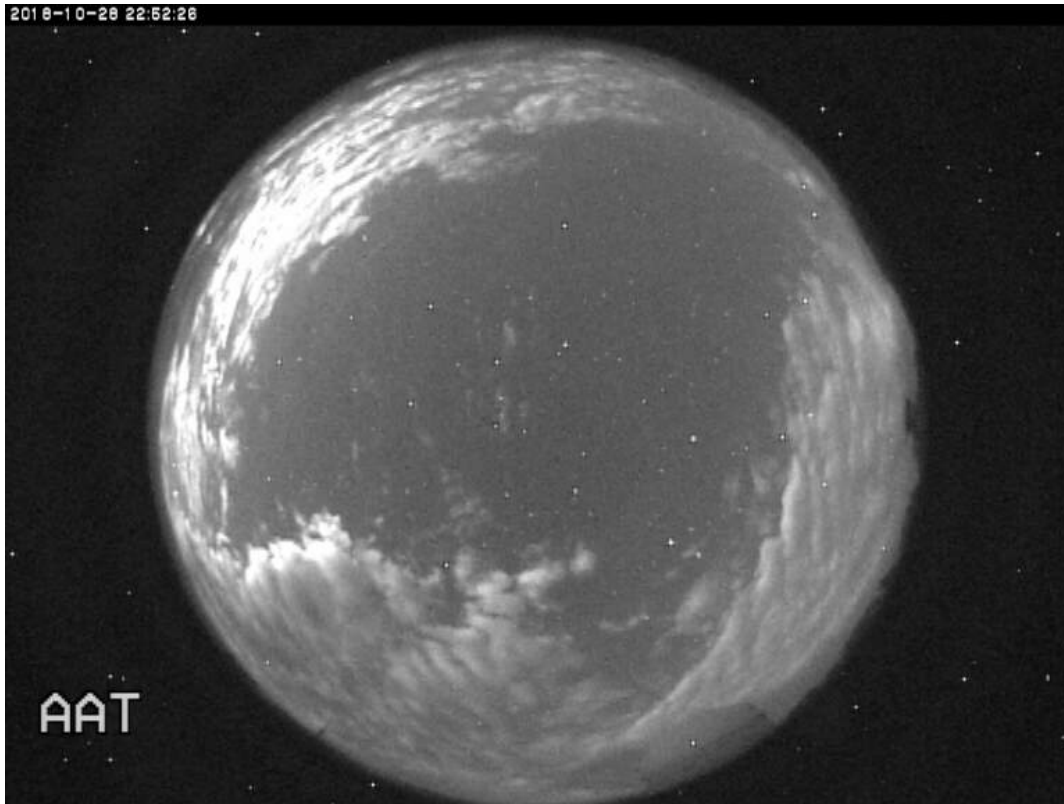
SSO: Clear overhead in ASC image (and sky temp says clear)
MODIS: Cloud detected *around* SSO
—> All good
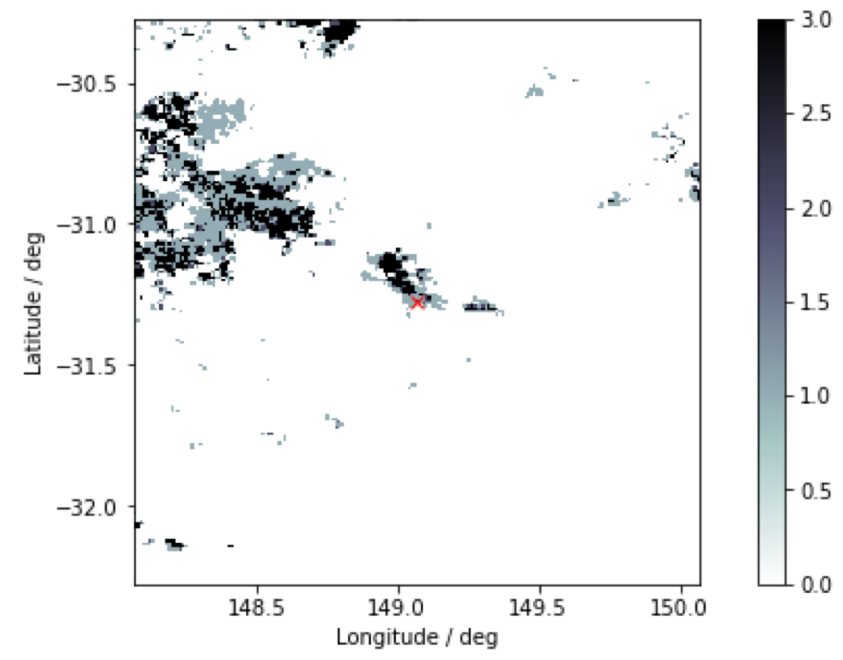
- white = cloudy around SSO, but with clear patch over SSO
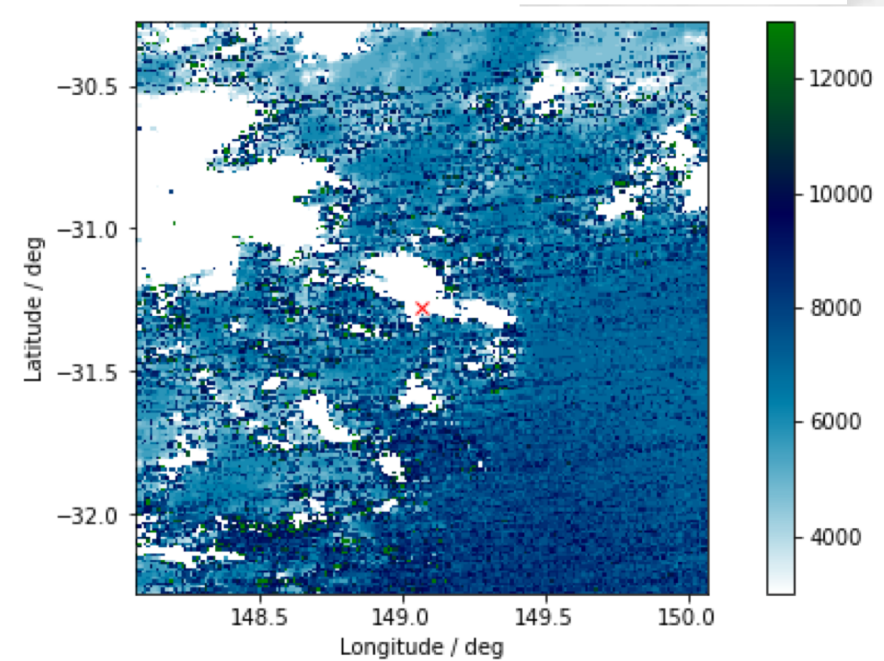
- mid-level cloud around SSO, very low cloud height (clear) over SSO

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SSO: Cloudiness (based on sky temperatures)

- Cloudiness = Fraction of night that is clear (SSO cloud mask >= 2)

- nearly twice as many fully clear nights as fully cloudy nights
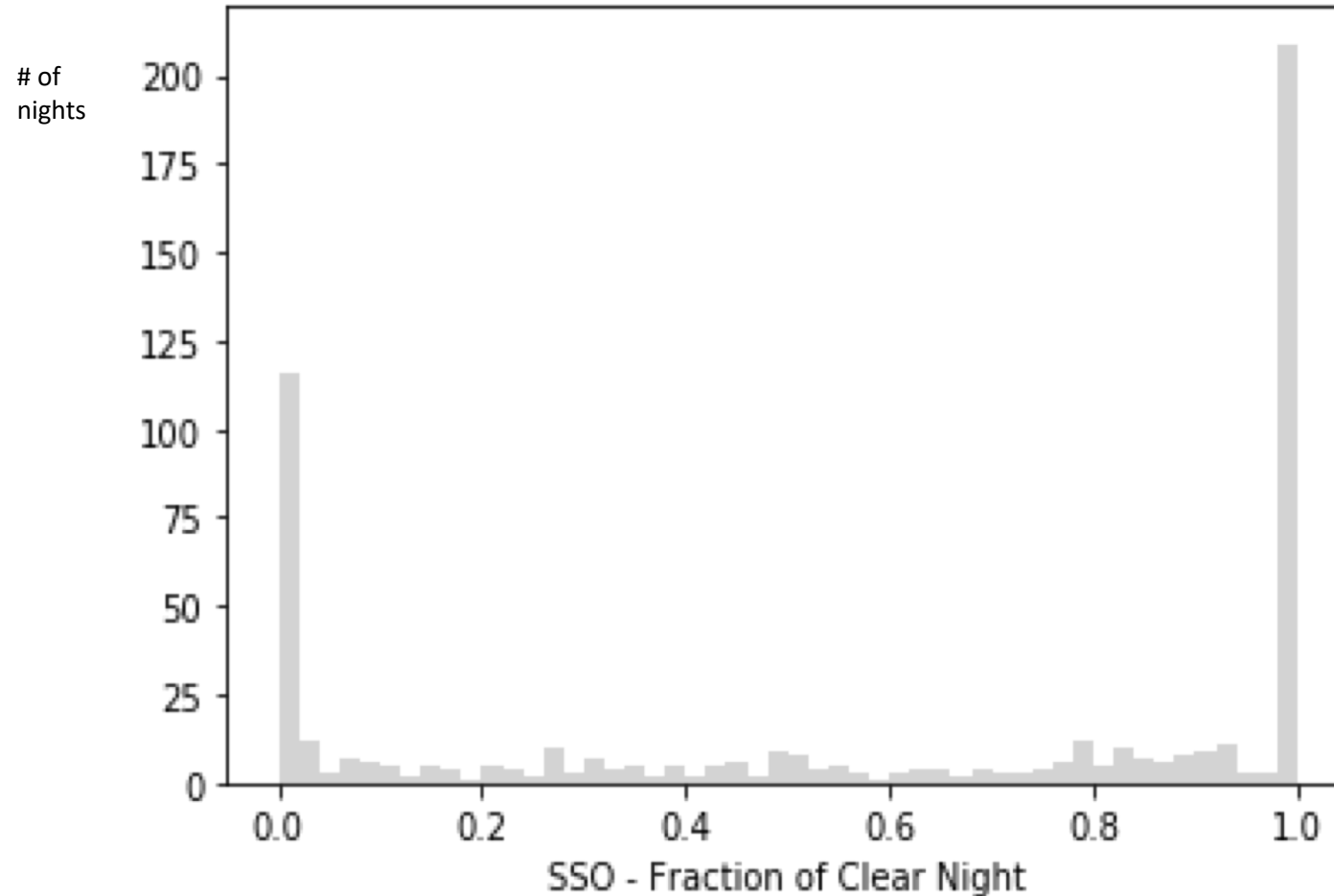
MODIS: Cloudiness

How good is the extrapolation from 1-2 nightly measurements to entire night?

- Cloudy nights: 24%

- Cloudy nights extrapolated: 39%

- Clear nights: 39%

- Clear nights extrapolated: 56%

~30% uncertainty from extrapolation

(Cloudy night = fraction of clear night < 10%)
(Clear night = fraction of clear night > 90%)
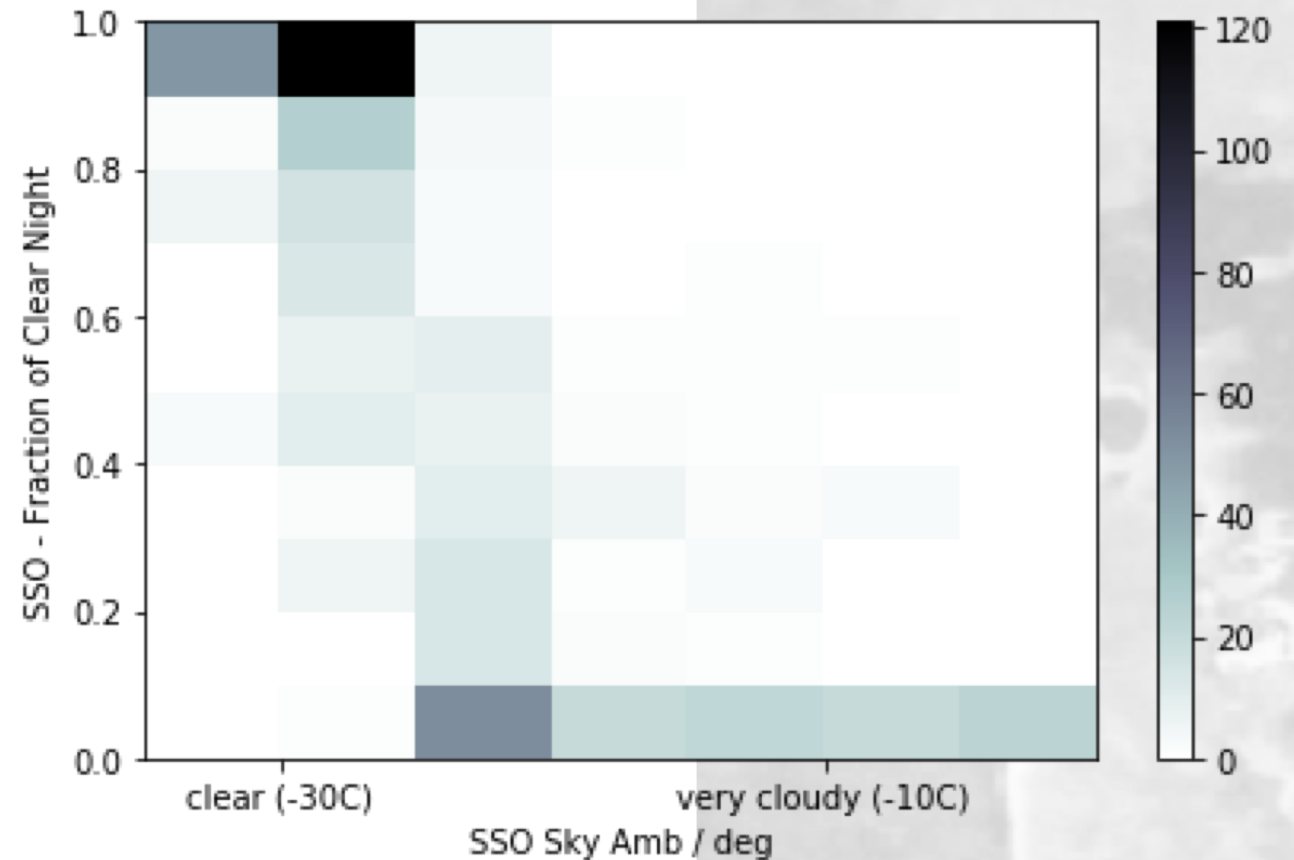
Caveat about Boltwood cloud sensor "clear" sky temperatures

- some MODIS passes showed inconsistencies between MODIS and SSO sky-temperature cloud flags (using Boltwood ground-based passive IR cloud monitor)

- e.g. MODIS indicated the presence of cloud, but SSO sky-temps suggested clear skies

- the conditions we use for SSO cloud monitor flags are:
  - very cloudy (0): > -10° C
  - probably cloudy (1): > -25° C
  - probably clear (2): < -25° C
  - clear (3): < -30° C

- SSO nominally < -25° C taken as clear skies (stated on the page referred to below)

- we adopted < -30° C for clear skies, as looking at the real-time AAT weather page at http://aat-ops.anu.edu.au/AATdatabase/met.html showed some cloud still around on occasions at ~ -25° C

Table of discrepant MODIS/SSO cloud flags : SSO indicates clear, MODIS indicates cloud

	sso_UTC+10	sso_Sky-Amb	sso_cloudiness	sso_cloudflag	modis_10km_cmask_1
465	2018-10-14 01:10:00	-35.5	0.861538	3.0	0.246154
468	2018-10-15 23:20:00	-34.6	1.000000	3.0	0.000000
469	2018-10-16 00:50:00	-31.4	1.000000	3.0	0.000000
489	2018-10-26 01:30:00	-42.3	1.000000	3.0	0.686567
492	2018-10-28 22:50:00	-35.4	0.539683	3.0	1.000000
504	2018-11-03 22:10:00	-40.5	1.000000	3.0	0.000000
505	2018-11-04 01:20:00	-41.1	1.000000	3.0	0.000000
506	2018-11-04 23:00:00	-33.3	0.983607	3.0	0.807229
520	2018-11-12 22:10:00	-36.2	0.916667	3.0	0.117647
521	2018-11-12 23:40:00	-36.4	0.916667	3.0	1.000000
542	2018-11-24 22:30:00	-30.5	0.482759	3.0	0.000000
545	2018-11-27 01:30:00	-34.5	0.465517	3.0	0.808824
546	2018-11-27 23:00:00	-32.5	0.467742	3.0	0.662338
555	2018-12-03 22:20:00	-33.0	1.000000	3.0	0.000000
556	2018-12-04 01:40:00	-39.1	1.000000	3.0	0.100000
559	2018-12-05 22:10:00	-35.6	1.000000	3.0	1.000000
586	2018-12-21 22:10:00	-38.2	1.000000	3.0	0.888889

sky temp = clear

cloudiness = mostly clear night (*based on sky temps*)

cloudflag = clear at time of pass (*based on sky temps*)

cmask = MODIS says cloud around SSO

- the numbers after pass ID and time are

  - sky temp (° C) : nominally < -30° C taken to be clear skies

  - sso_cloudiness = fraction of night with temp-derived cloud flag >= 2 (a higher value = more of the night is clear, i.e. 1 is clear all night)

  - sso_cloud_flag (based on sky temps, as defined earlier)

  - modis_10km_cmask_1 is an average of the following MODIS cloud flags (a MODIS pixel is 1km-square) taken over a 10km-radius circle centred on SSO, based on the following
    - 0 = very cloudy
    - 1 = probably cloudy
    - 2 = probably clear
    - 3= clear
    - but, as an average is taken, the value may not be an integer
    - all values in the table indicate the presence of significant amounts of cloud in the MODIS data

- for these passes, the relevant SSO ASC images were checked for the visible presence of cloud

- in all cases, it was found that at least some cloud was present in the ASC images

  - at least cirrus, sometimes very thin (it is known that such cloud may not be picked up by passive IR cloud sensors)

  - sometimes there is a clear patch overhead (or near overhead) at the time of the MODIS pass, but with cloud otherwise present (this should show up in the *sso_cloudiness* parameter, or in the MODIS maps)

  - on nights with very low clear-sky values of sky_ambient, cloud can be present even when the sky temp is at values that are taken to indicate clear skies

465 2018/10/14 | T = -35.5° C | sso_cloudiness = 0.86 (*mostly clear night*) | MODIS 10km_cmask = 0.25 (*lots of cloud*)

489 2018/10/26 | T = -42.3° C | sso_cloudiness = 1.00 (*clear night*) | MODIS 10km_cmask = 0.69 (*significant cloud*)

520 2018/11/12 | T = -36.2° C | sso_cloudiness = 0.92 (*mostly clear night*) | MODIS 10km_cmask = 0.12 (*very cloudy*)

- the night of pass 489 (which was at 20181025 15:30 UT) had very low sky temps, down to ~ -47° C

- at the time of the two ASC images below (10 minutes after pass 489), the sky temps were around -37.9° C, well below the nominal clear-sky limit

  - but there was significant cloud present

- so it would seem that (at least for SSO- perhaps there are local variations?) the sky temperature values should be taken with a dose of caution when it comes to assigning clear-sky status

- perhaps the usual statement that "sky temperatures below x °C indicate clear skies" might be reworded as

  - "...in general, it is found that clear skies will have sky temperatures below x °C, but this does not preclude the possibility of some cloud being present for such temperatures"

Summary

- There is a generally good agreement between satellite-based MODIS cloud characterisation and ground-based cloud characterisation based on passive IR cloud monitoring (sky temperatures)

- extrapolating from one or two MODIS passes on a night, to a classification of the entire night based just on those limited measurements, is not unreasonable- but, of course, not perfect...

- nights of very low *clear-sky* sky temperatures can show periods of significant cloud which still yield associated sky temperatures below the nominal clear-sky limiting temperature

   - *such a limiting temperature is not a 100% guarantee of clear skies below that sky temperature*

- conclude that cloudiness characterisation based on MODIS-only data is a useful approach when no ground-based data are available, or as another mode of charcterisation when such data are available