Monitoring the Terrestrial Environment

Fire and Haze

Chia Aik Song
Research Scientist /
Head of Fire Monitoring,
CRISP, NUS

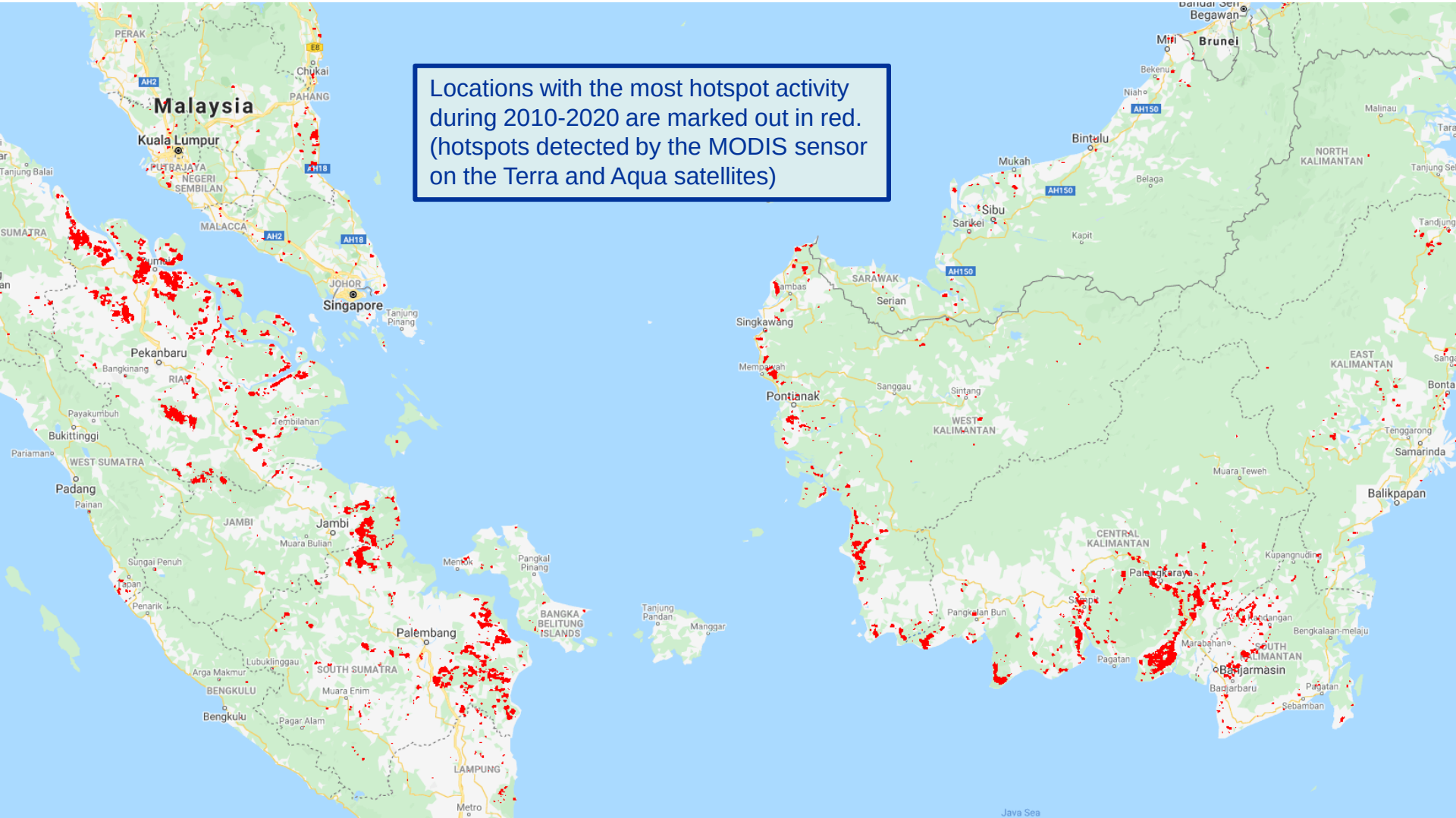
Outline

- Hotspots: Satellite thermal detection of fire
- Visual detection of smoke plumes in optical satellite images
- The CRISP regional fire monitoring operation
- Major haze events in our region in the past 25 years which affected Singapore

Haze from Fire

- In many years, Singapore is affected by haze – air pollution from smoke carried through the atmosphere from fires.
- This mostly happens during the period from July to October.
- Because of dry weather in Sumatra and Kalimantan during this period, large fires often flare up there.
- These fires generate smoke which often gets carried by winds to neighbouring regions.

Where are the suspected fires?



What are “Hotspots”?

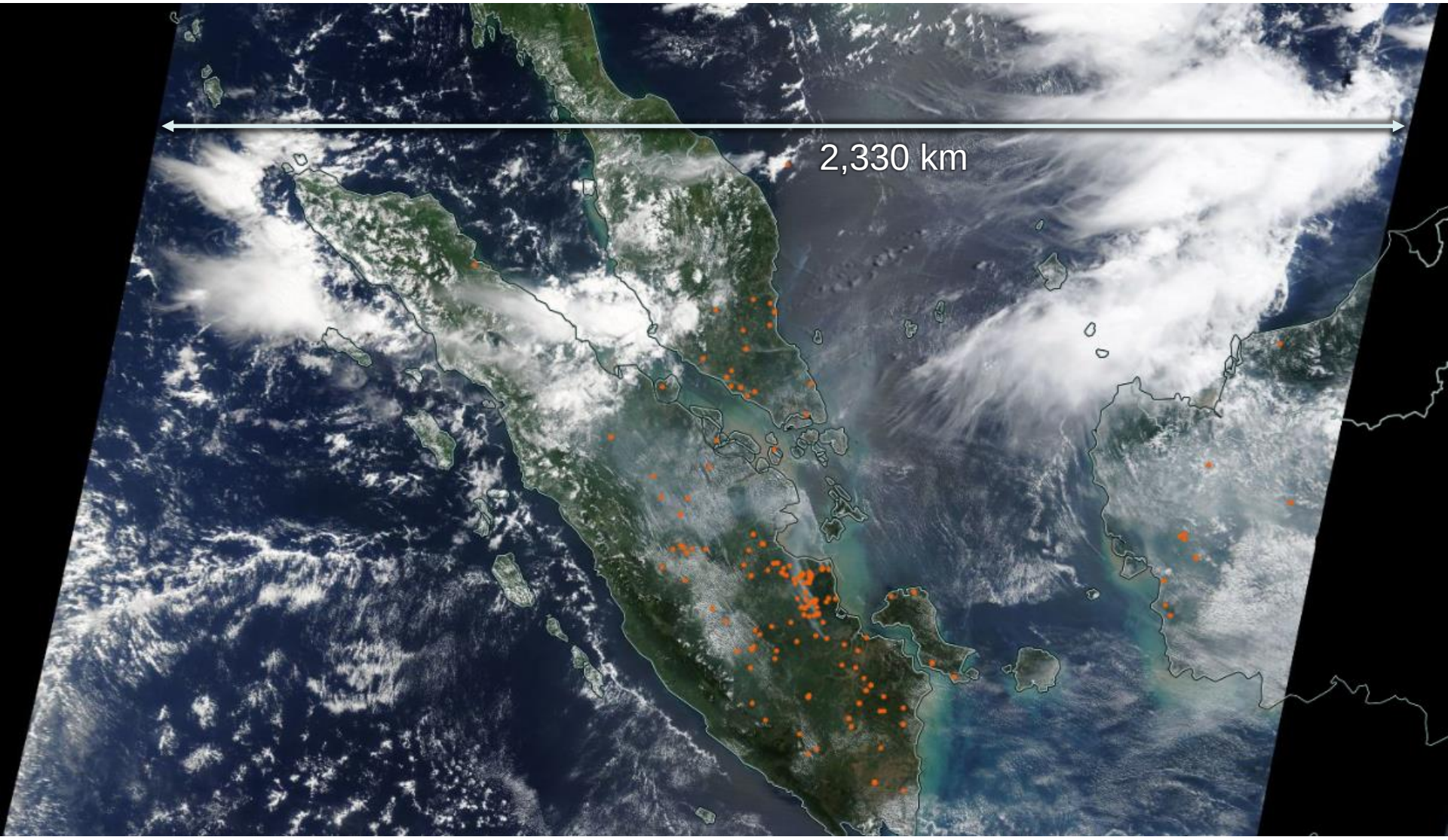
- Every object in our environment emits electromagnetic radiation in the thermal infrared region (in a range of wavelengths around 10 μm). The spectrum emitted depends on the temperature of the object. Thermal imaging cameras make use of this.
- Thermal infrared sensors (around 4 and 11 μm) on satellites can be used to estimate the temperature on the ground.
- Areas with a high estimated temperature* are marked out as “hotspots”.
- These hotspots are locations where fire is suspected.

* This is a simplification;
actual algorithm is a bit more complicated!

Thermal imager in a public area

Satellite hotspot detection

- So now you know – when you read in the news about “hotspots detected by satellites” – these *are* literally spots on the Earth which are hot!
- Hotspot detection is usually carried out by wide-coverage, low-resolution (~1km) environmental satellites, like Terra, Aqua and the NOAA series of satellites.
- An algorithm to detect hotspots is run over all pixels in the satellite image, and locations which are detected as hotspots are listed out in text format.


2,330 km

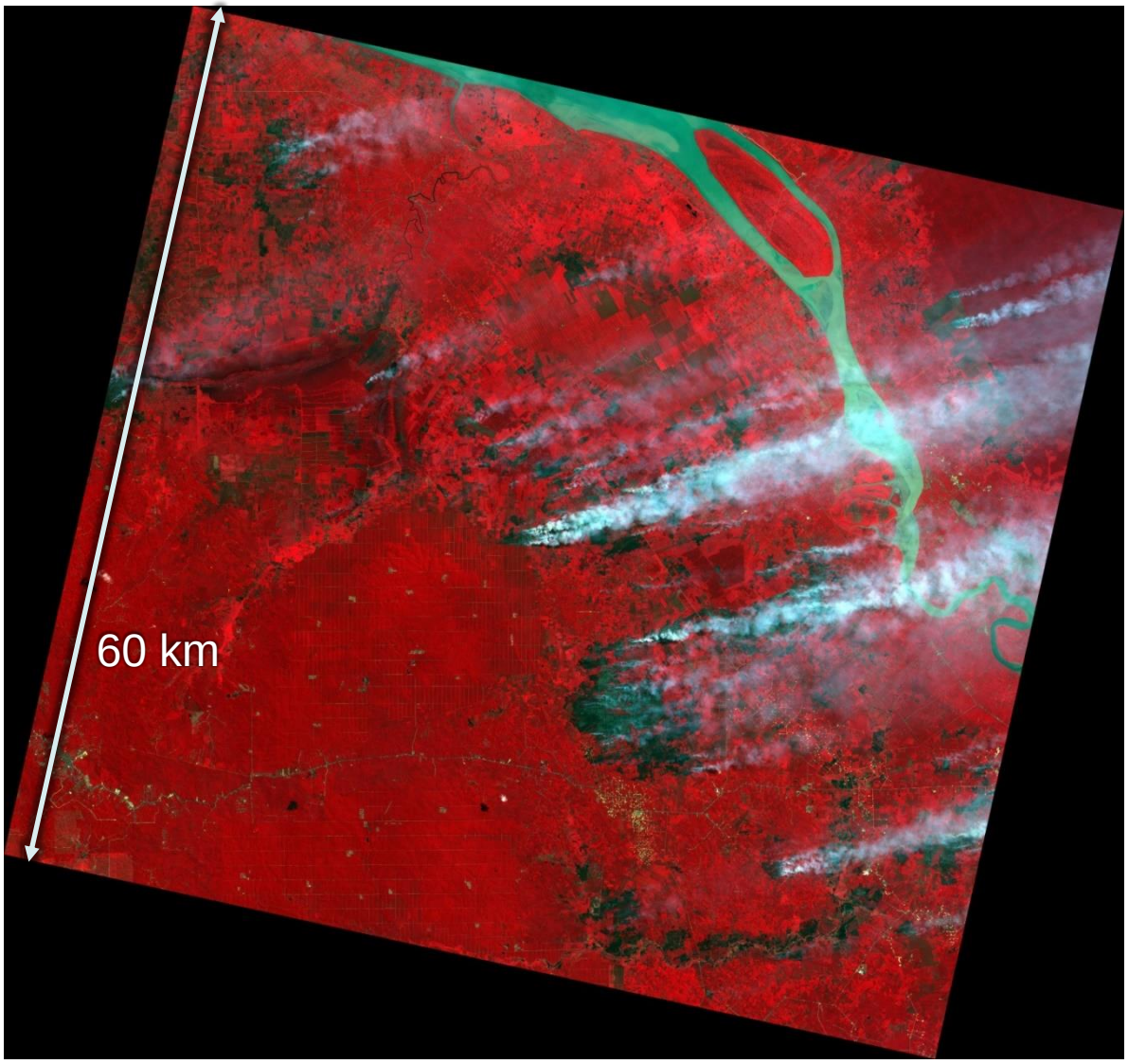
Hotspot does not necessarily mean fire!

- However, a location which is detected as a hotspot does not mean there is certainly a fire there.
- This is because it may be a false alarm: E.g. a large patch of bare land in a forested region on a hot day can be tagged as a hotspot, even though there may be no fire there at all.
- Conversely, some real fires may be missed by the hotspot algorithm. E.g. fire can smoulder underground in peat swamp areas – they do not emit a lot of infrared radiation, but can still generate a lot of smoke.
- In summary, the detection of a hotspot does not mean there is 100% a fire there. Conversely, if there is no hotspot detected at a location it also does not mean there is 100% no fire there.

The CRISP Fire Monitoring Operation – The beginning

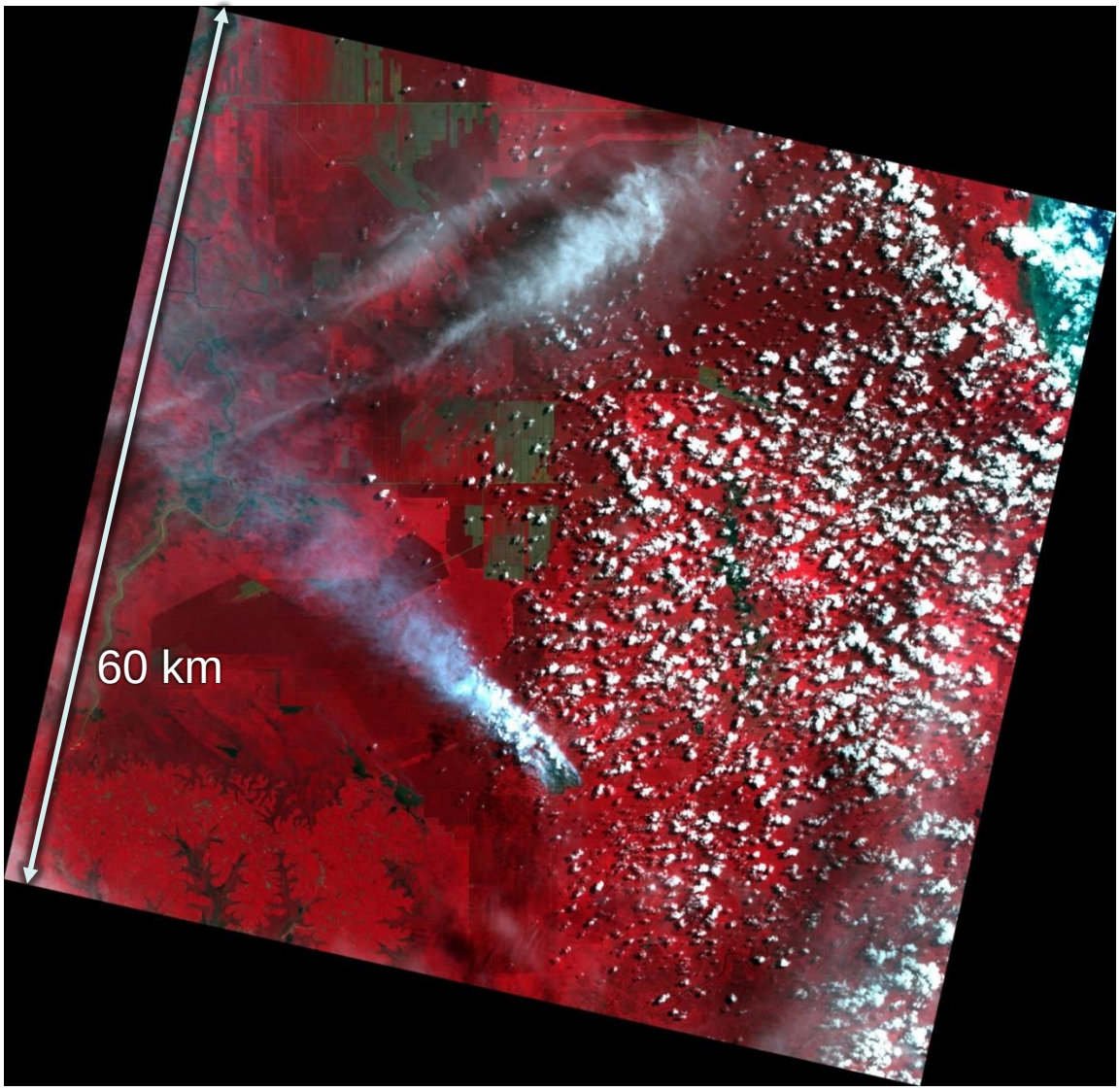
- Severe haze has many social and economic consequences – it is a health hazard, disrupts human activities and affects visibility and hence transportation.
- Because of this, the Singapore government is obviously keen to track the fires which are the cause of the haze, in a reliable way.
- During the 1997 haze event, CRISP scientists noticed that the smoke plume from fires can be detected unambiguously on high-resolution SPOT satellite images.
- A daily regional fire monitoring operation was started by CRISP for and supported by NEA (then known as ENV) in 1998, using high-resolution SPOT satellites.

Visual Identification of Fires



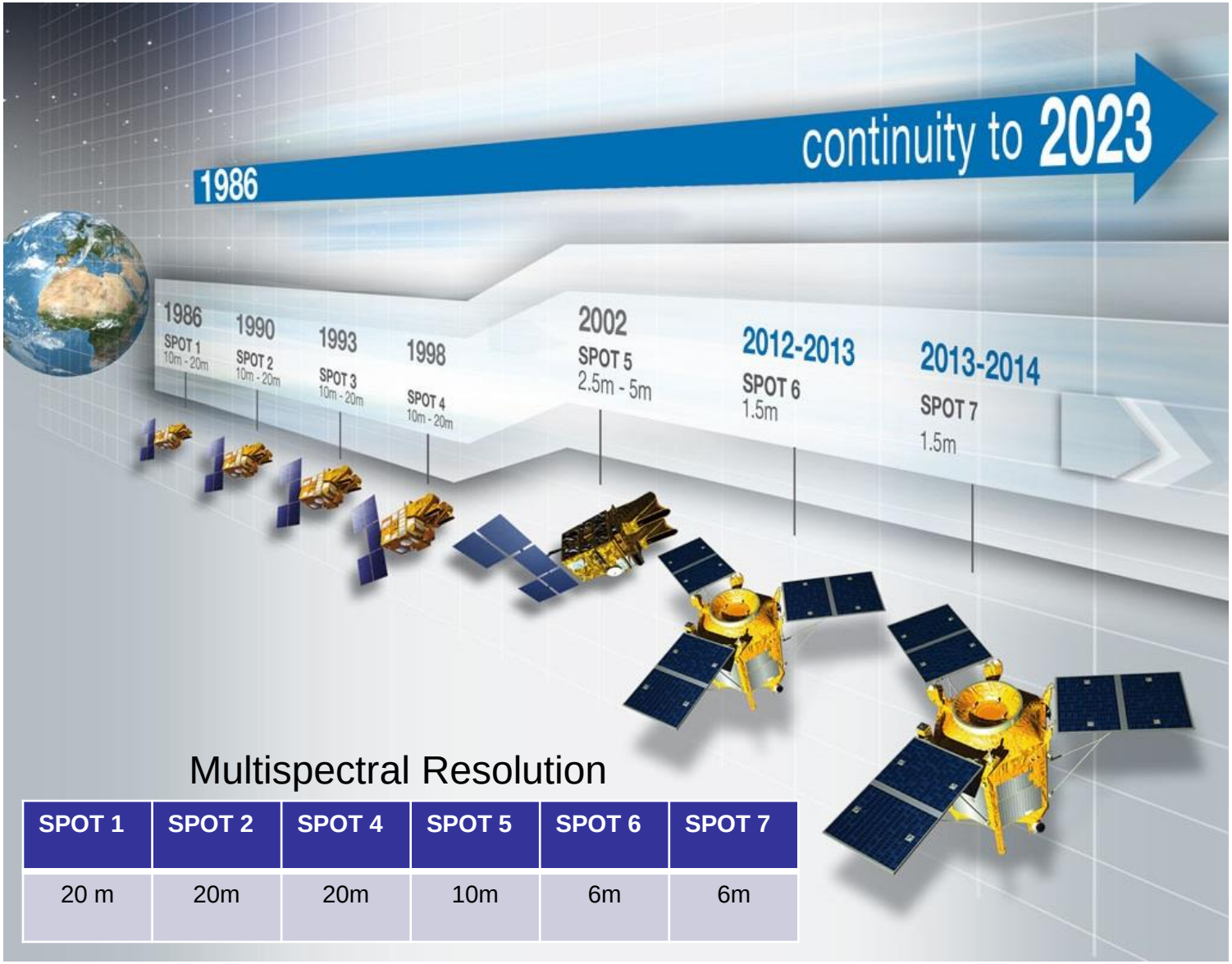
- SPOT multispectral optical satellite image.
- False colour image: R/G/B=NIR/R/G
- Fires detected by identifying the smoke plumes from the fires.
- Often bluish-grey smoke can be distinguished from white clouds.
- Also provides a good contrast between vegetated and non-vegetated areas.

Cloudy Fire Images



- Cloud cover is usually heavy in the SEA region.
- Most satellite images, including the ones with fire, will be cloudy.
- Experience is often needed to distinguish the fires from clouds.
- In worse cases where it is extremely cloudy, very hard to distinguish fires from the obscuring clouds.

Changes in SPOT Satellite Technology

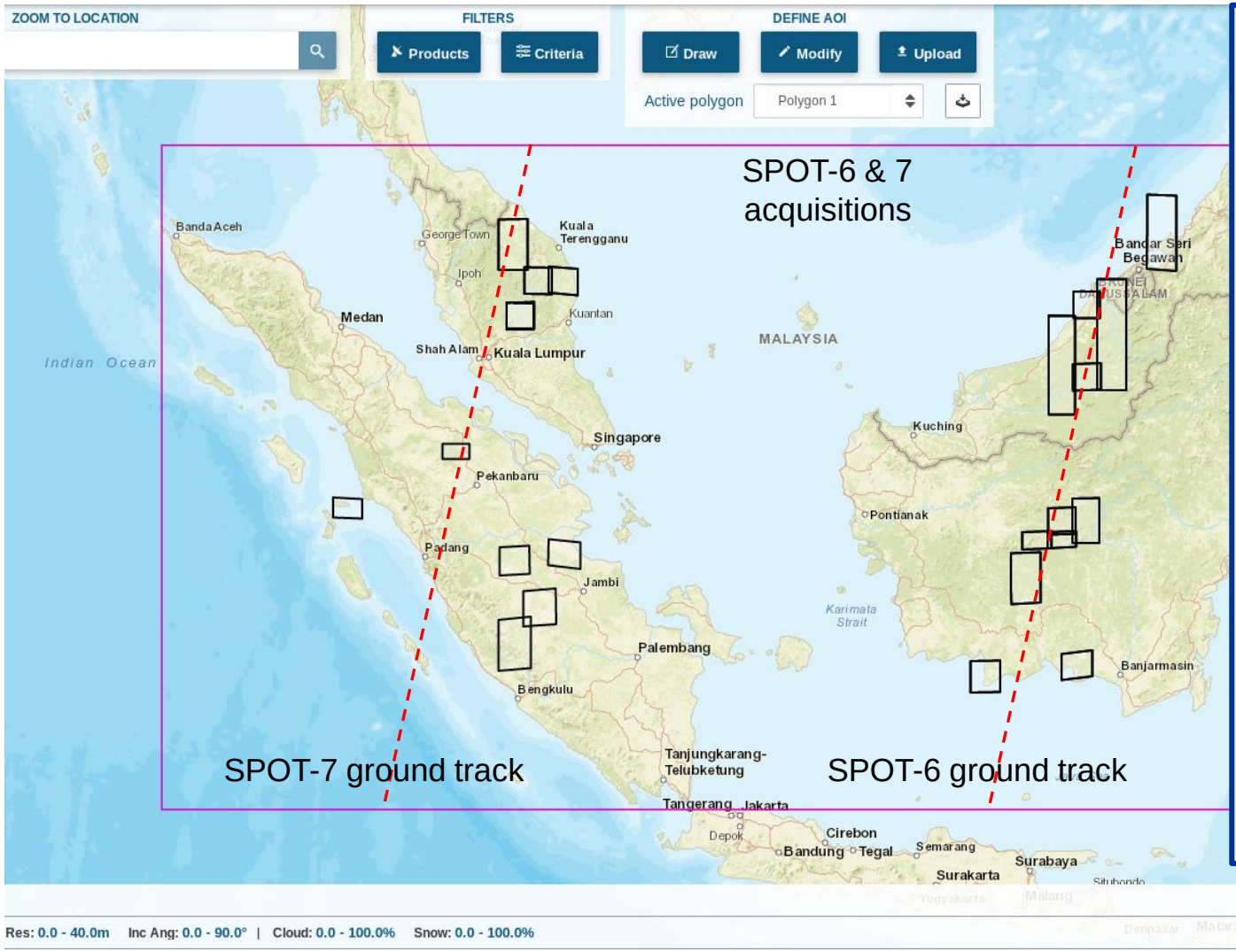


Multispectral Resolution

SPOT 1	SPOT 2	SPOT 4	SPOT 5	SPOT 6	SPOT 7
20 m	20m	20m	10m	6m	6m

Diagram credit: Airbus DS

Images acquired by SPOT-6 & 7 around SG in one day



- Tasking = Telling the satellite where to capture images.
- Satellite travels along orbital track (in red) and turns to capture images on either side of the track.
- The satellites must be tasked 1 day in advance to image your specified area of interest.
- Targets of interest → CRISP ground station → Airbus DS

CRISP Fire Monitoring with SPOT: Workflow

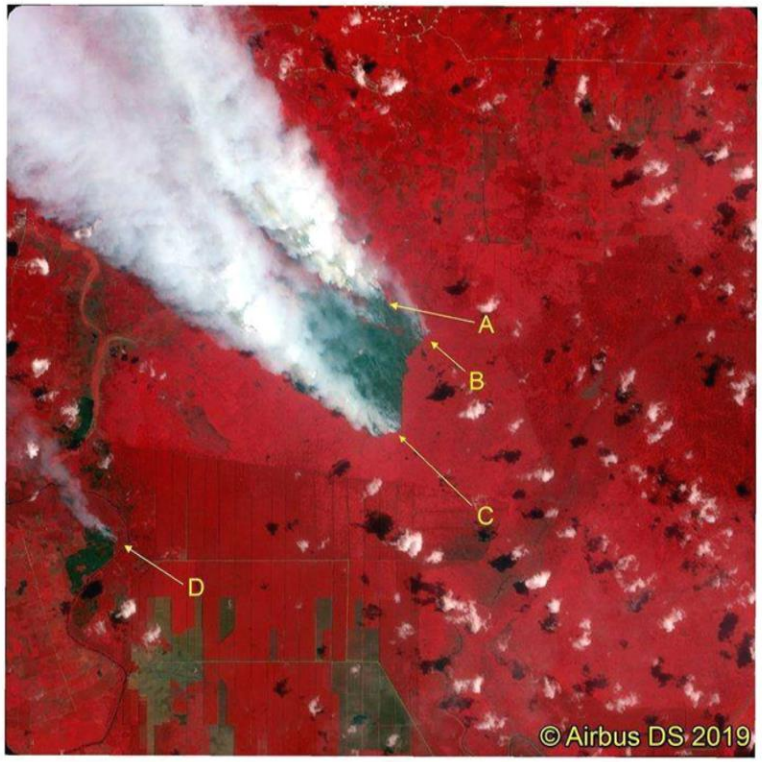
Tasking → Scanning → Processing

1. Task SPOT satellite to image areas where fires are suspected.
2. SPOT satellite captures image the next day.
3. Scan the images for signs of fire.
4. Processing: Mark out detected fires in image and deliver to NEA with additional info.

Our daily fire monitoring operation utilised SPOT data exclusively, until 2018.

Annotated SPOT Fire Image

Fire Image in South Sumatra
15th August 2019 03:19:40 (UTC)



0 1 2 4 6 8 Kilometres

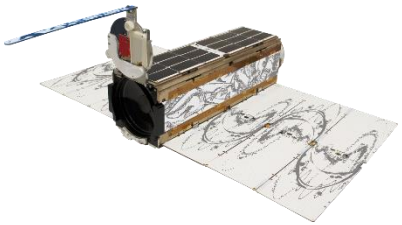
AIRBUS DEFENCE & SPACE

CRISP
National University of Singapore

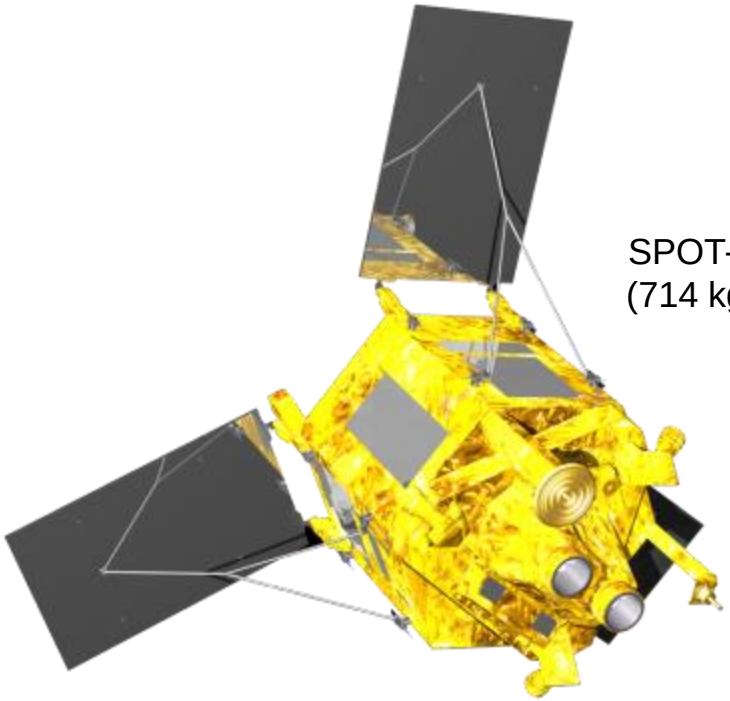
The PlanetScope Constellation

- A constellation of 120+ Dove nanosatellites, operated by Planet Labs, a US company set up by a group of former NASA scientists and engineers.
- These are small, simple satellites which are unable to change their pointing direction when taking images, i.e., the satellites can only capture images in one fixed direction downwards.
- But due to the large number of satellites, the constellation provides good coverage of the Earth.

Dove-2
(5.8 kg)



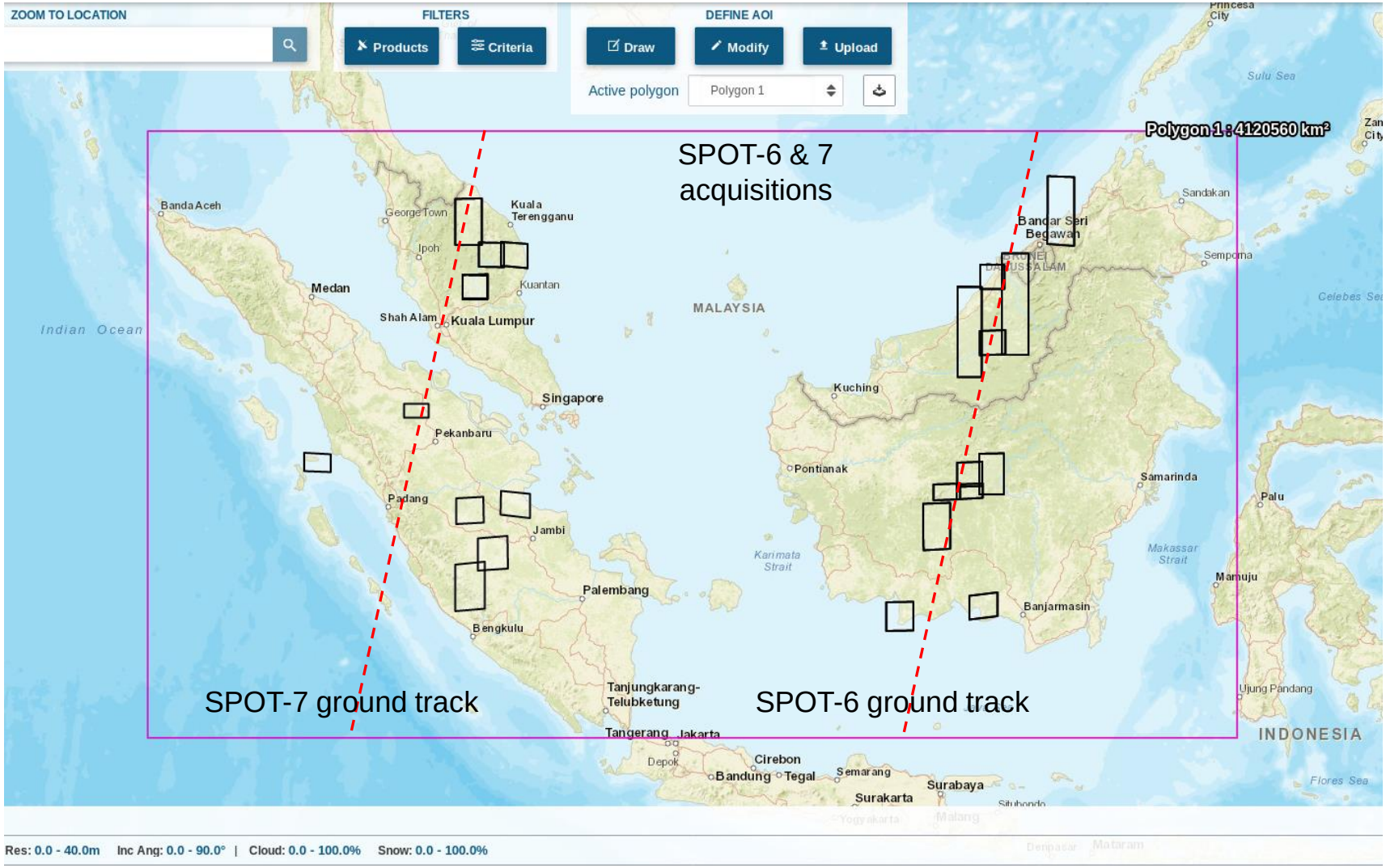
SPOT-7
(714 kg)



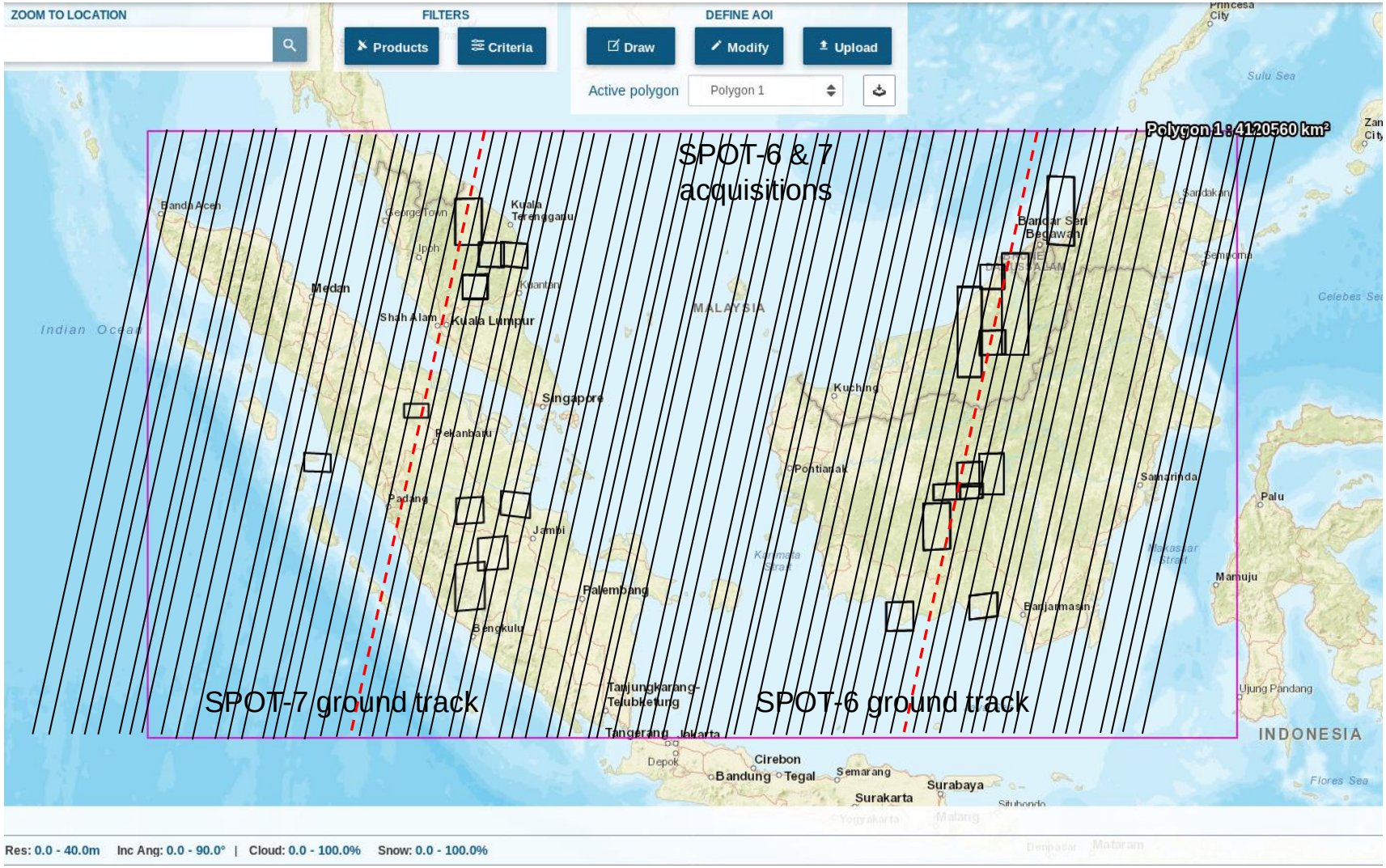
PlanetScope for Fire Monitoring

- In 2018 we started incorporating PlanetScope data into our fire monitoring operation.
- Comparison with SPOT-6/7:
  - Both have 4-band NIR/Red/Green/Blue imagery.
  - Both have spatial resolutions in the same order of magnitude: 3.9m for PlanetScope and 6m for SPOT (multispectral).
- **Main difference: SPOT needs to be tasked, whereas the PlanetScope constellation simply acquires all imagery wherever their sensors cover.**
- If the tasked SPOT image happens to be very cloudy, then we are out of luck and will have to try again another day.
- Because there are more than 100 satellites in the PlanetScope constellation, there is almost complete coverage of the land every day.

Images acquired by SPOT-6 & 7 around SG in one day

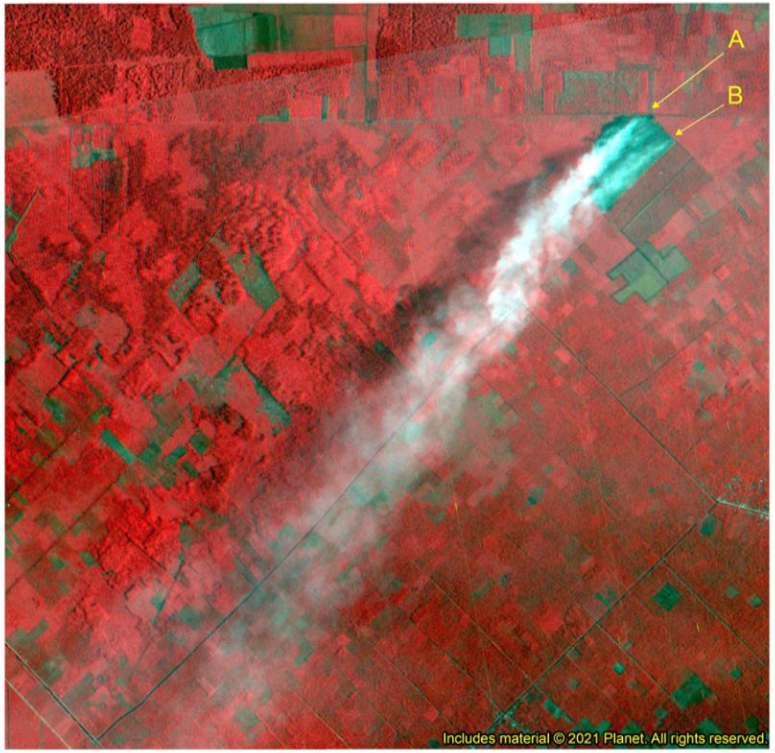


Example to illustrate PlanetScope Dove satellite tracks



Annotated Fire Image

Fire Image in Riau, Sumatra
9th March 2021 01:11:42 (UTC)



0 0.25 0.5 1 1.5 2
Kilometres

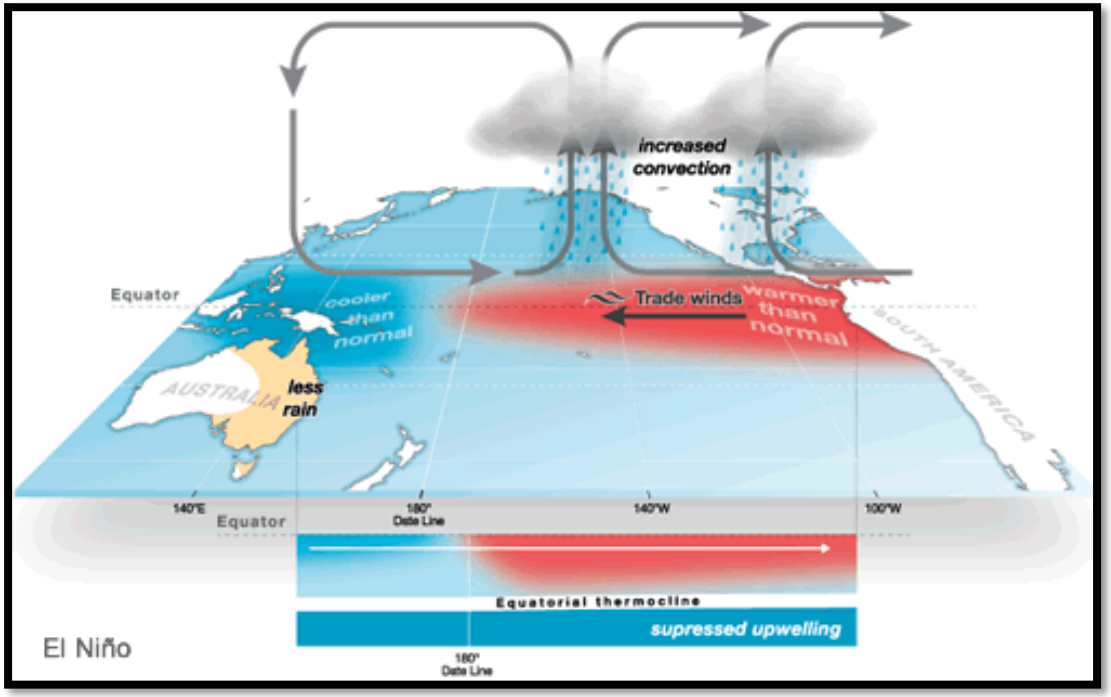
Major Haze events in Insular Southeast Asia

- Vegetation fires occur every year in Southeast Asia. In Mainland Southeast Asia (or Indochina), the main burning period is from November to March during the dry season.
- For Insular Southeast Asia, there are two fire seasons, the main one from July to November, and a smaller season from February to April, both coinciding with periods of drier weather.
- Severe fire events in Insular Southeast Asia brought serious air pollution to Singapore.
- Although fires occur yearly, they can be made worse by climate patterns like ENSO.

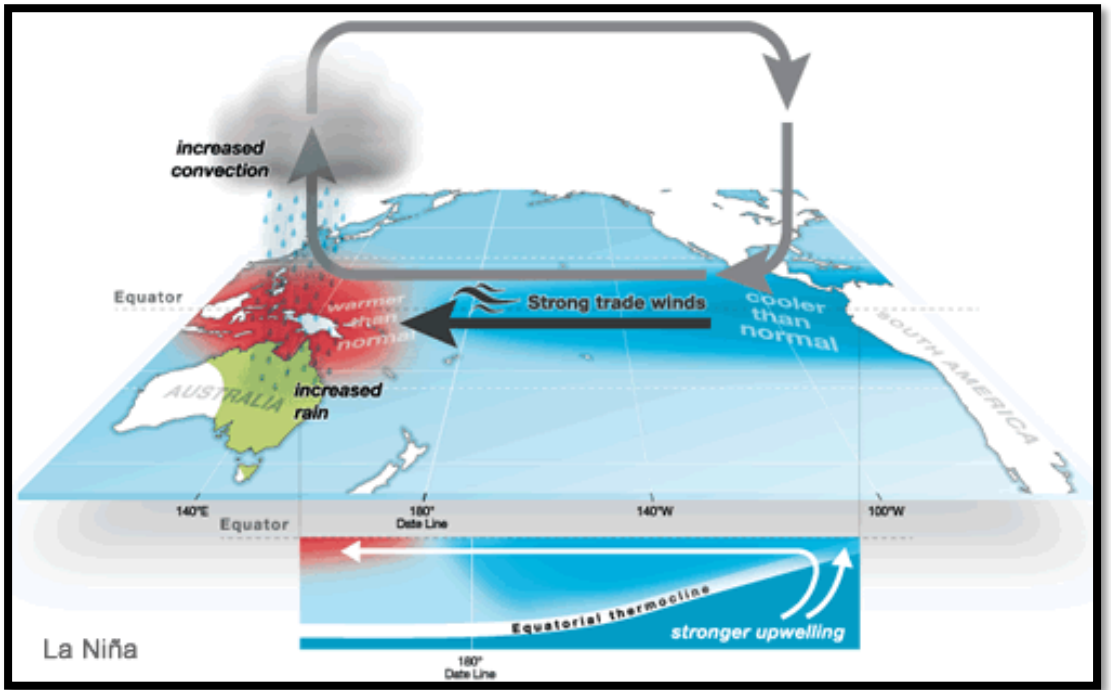
Insular / Maritime Southeast Asia

The El Niño-Southern Oscillation (ENSO)

- El Niño and La Niña are the two phases of a recurring climate pattern across the tropical Pacific — the El Niño-Southern Oscillation, or “ENSO” for short.
- The pattern can shift back and forth irregularly every two to seven years, and each phase triggers predictable disruptions of temperature, precipitation, and winds around the Pacific Ocean.
- Positive phase (El Niño)
  - Eastern Pacific: Higher than normal SST, more convection, more rain
  - Western Pacific: Lower than normal SST, less rain
- Negative phase (La Niña)
  - Eastern Pacific: Lower than normal SST, less rain
  - Western Pacific: Higher than normal SST, more convection, more rain



Positive phase – higher fire danger in Indonesia

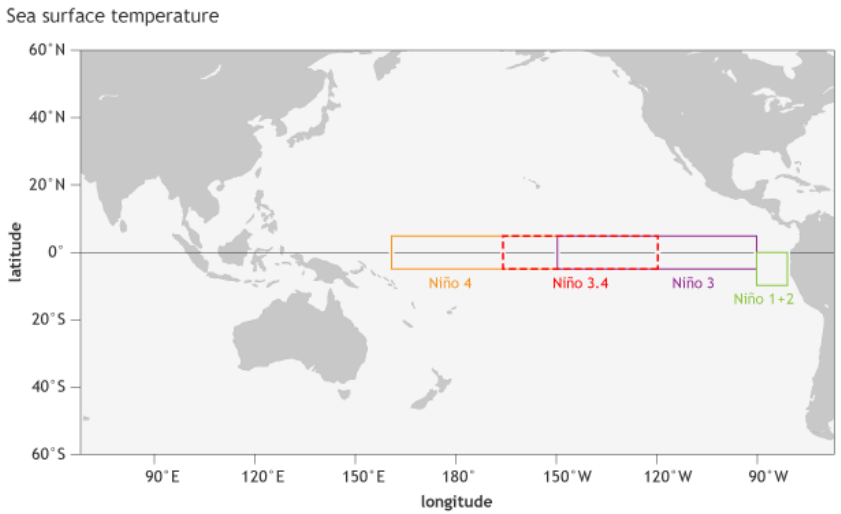


Negative phase – lower fire danger in Indonesia

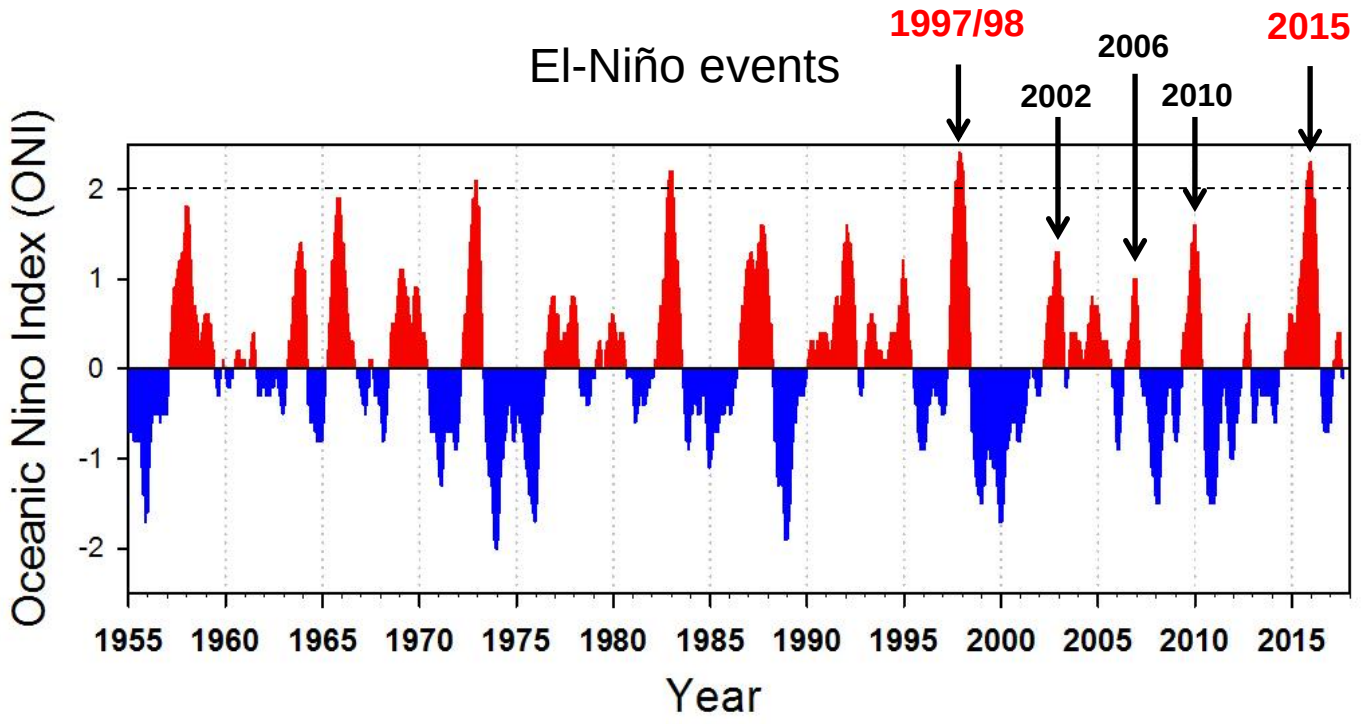
Diagram credit:
Australian Bureau of Meteorology

ENSO Indices

- How to tell which phase we are in right now?
- Various indices have and are being used to indicate which phase we are in – one number which can indicate the state of ENSO
- Oceanic Niño Index (ONI) – main index used by NOAA
- The ONI tracks the sea surface temperatures in the Niño 3.4 region
  - an area of the east-central tropical Pacific between 120°-170°W
- Calculation: 3-mth mean SST minus the 30-yr mean SST
- This value represents the SST anomaly in the Eastern Pacific.

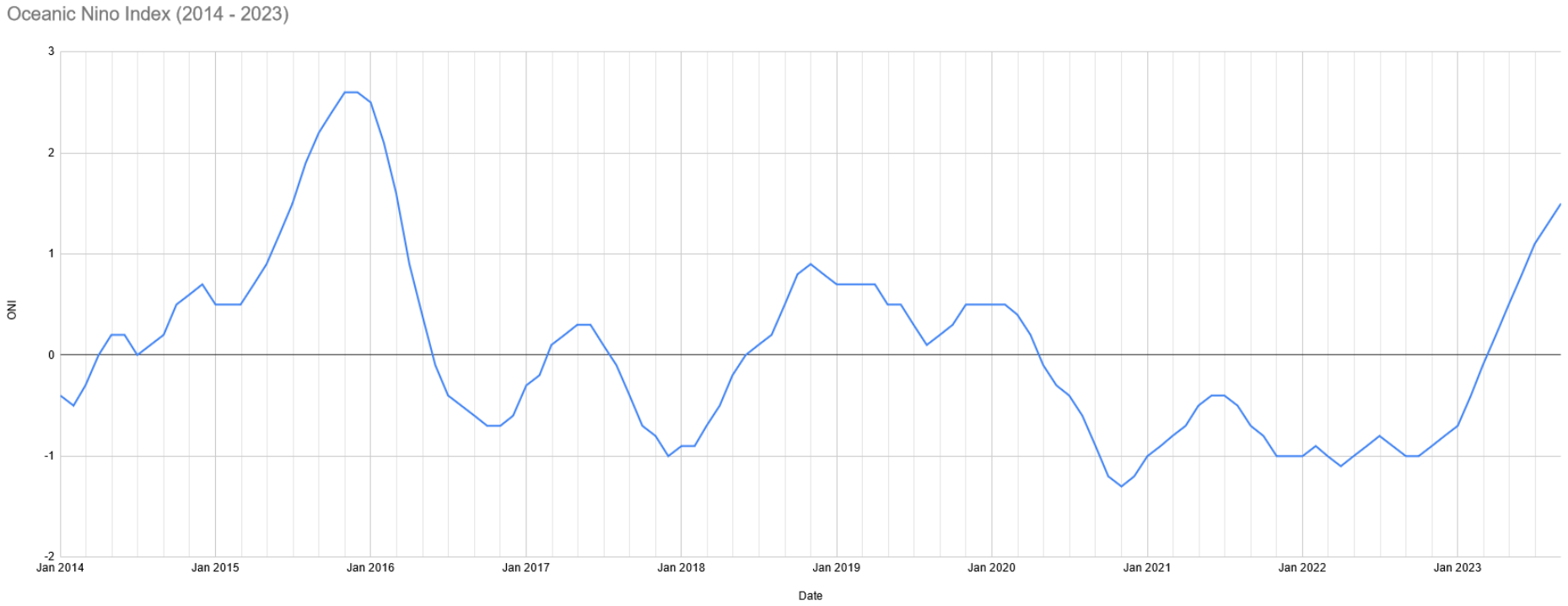


Severe El Niño → Severe fire events



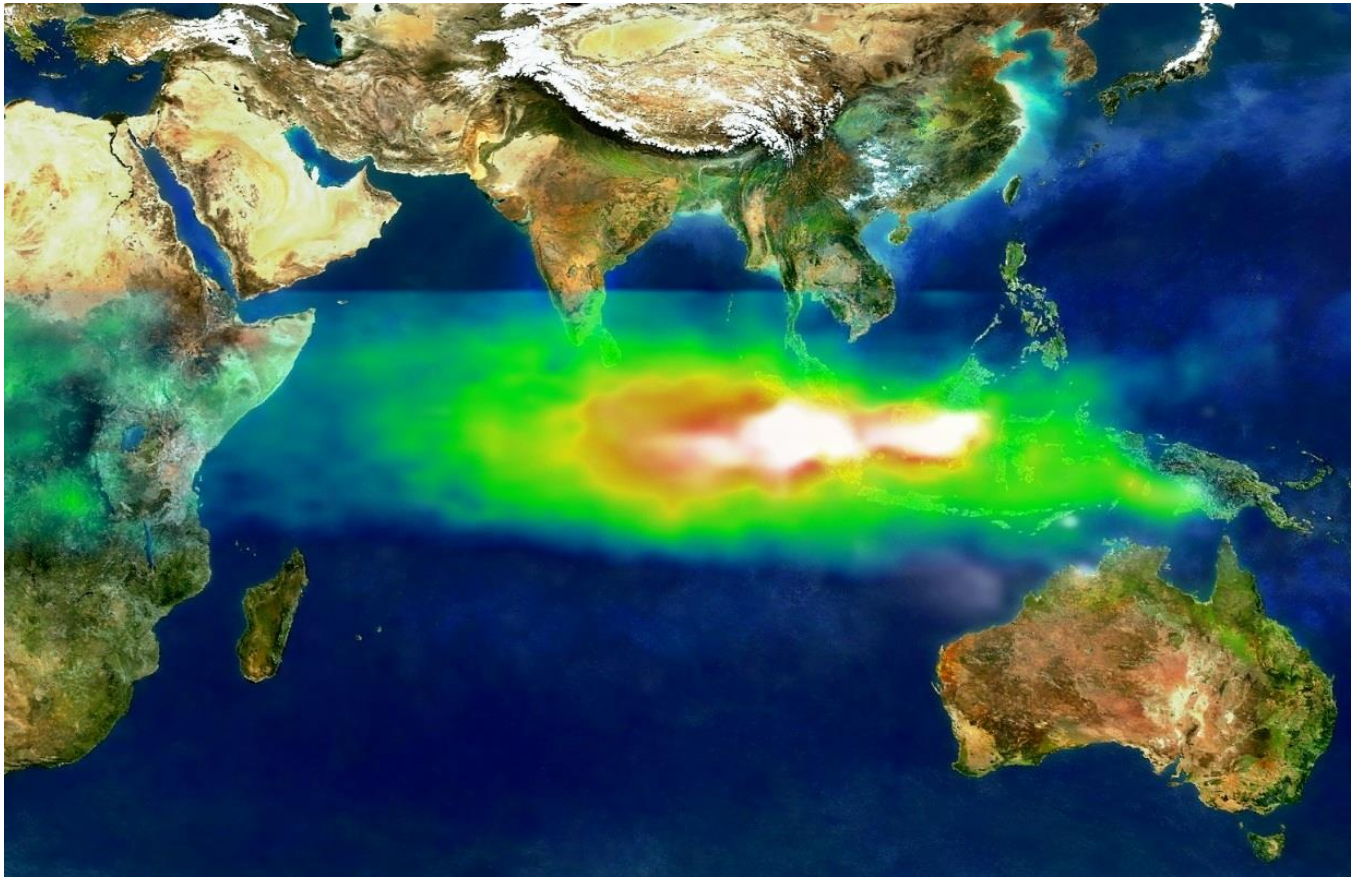
- When the ONI index goes above +2, we have super-El Niño events, with extreme dry weather in the region.
- And indeed, the Southeast Asia fire events of 1997 and 2015 were the worst ever on record.
- In both cases, numerous fires burned out of control and generated smoke haze which blanketed a large part of Southeast Asia for several months.

Recent ONI graph

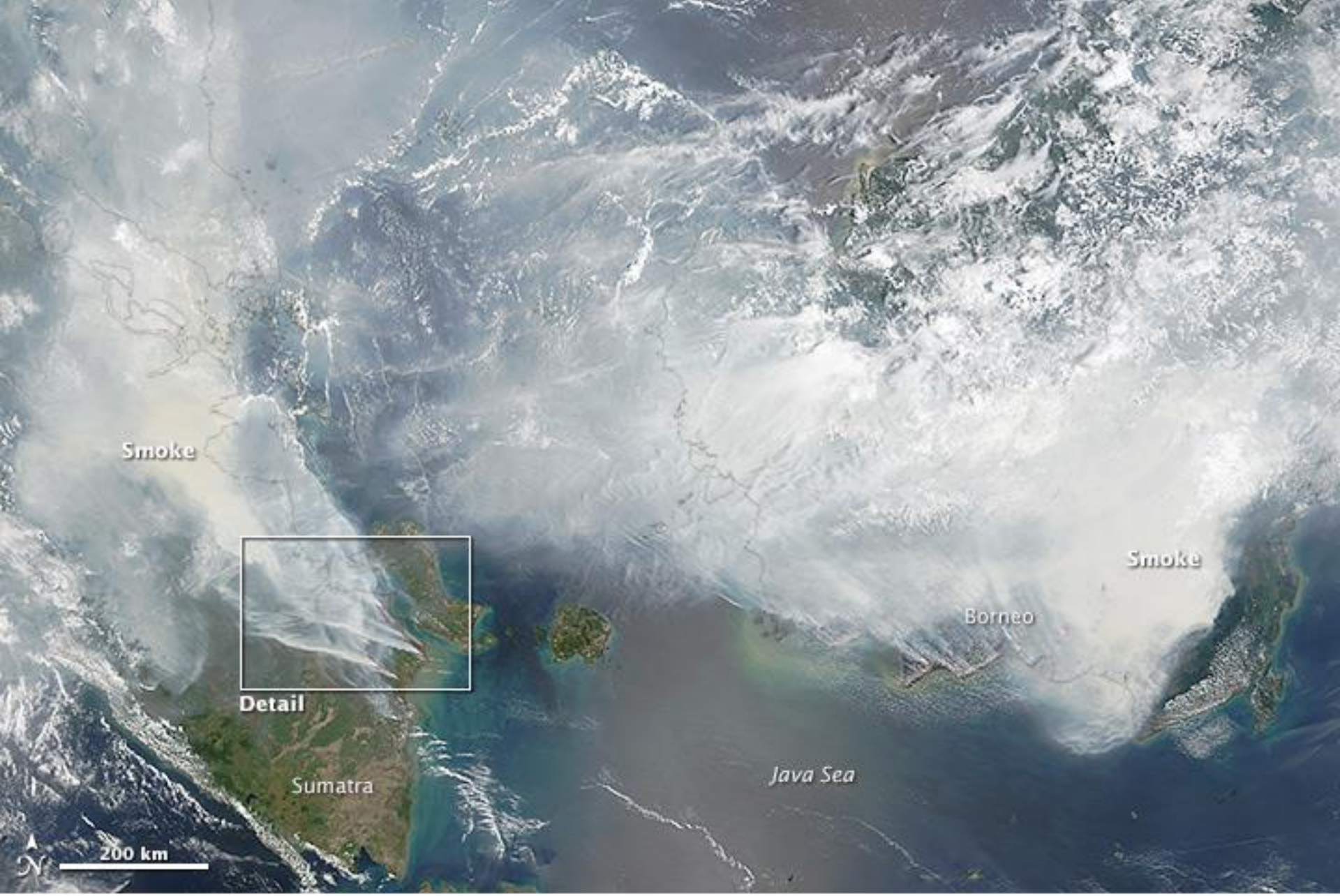


- The fire situation in the past few years (2020-2022) has been relatively quiet – coinciding with a La Niña episode.
- This year, a major El Niño event has begun, and is still continuing.

Air pollution caused by the 1997 fires



Pollution over Insular Southeast Asia and the Indian Ocean on October 22, 1997, detected by the TOMS-EP satellite. White pixels denote the aerosols (smoke) in the vicinity of the fires. Green, yellow, and red pixels represent increasing amounts of ozone generated by the smoke from the fires and spreading to neighbouring regions.

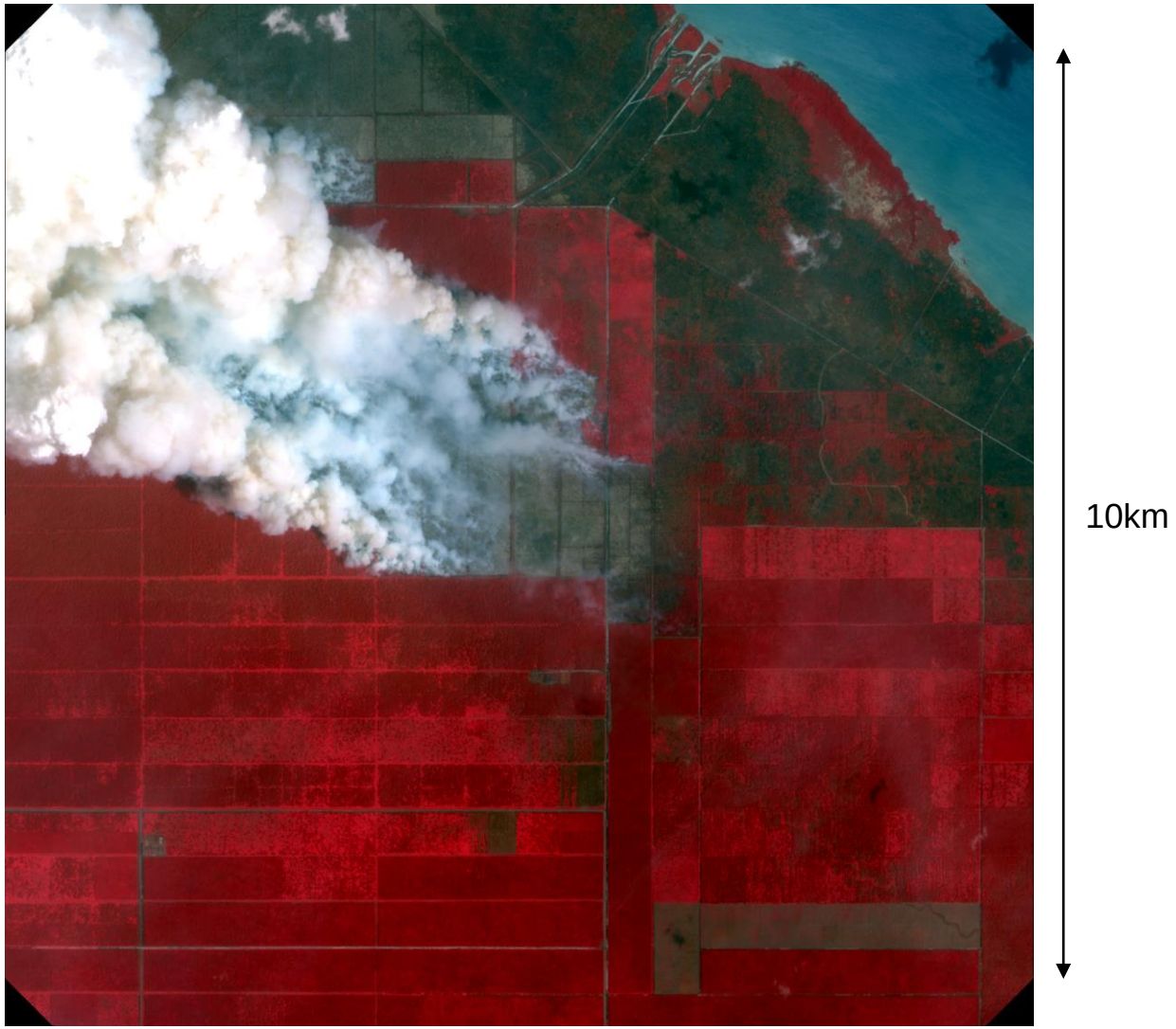


Terra MODIS true colour image, 24th Sep 2015

Previous image (24th Sep 2015), zoomed in to corner of Sumatra; hotspots marked out in orange

Terra MODIS true colour image, 20th Oct 2015; hotspots marked out in orange

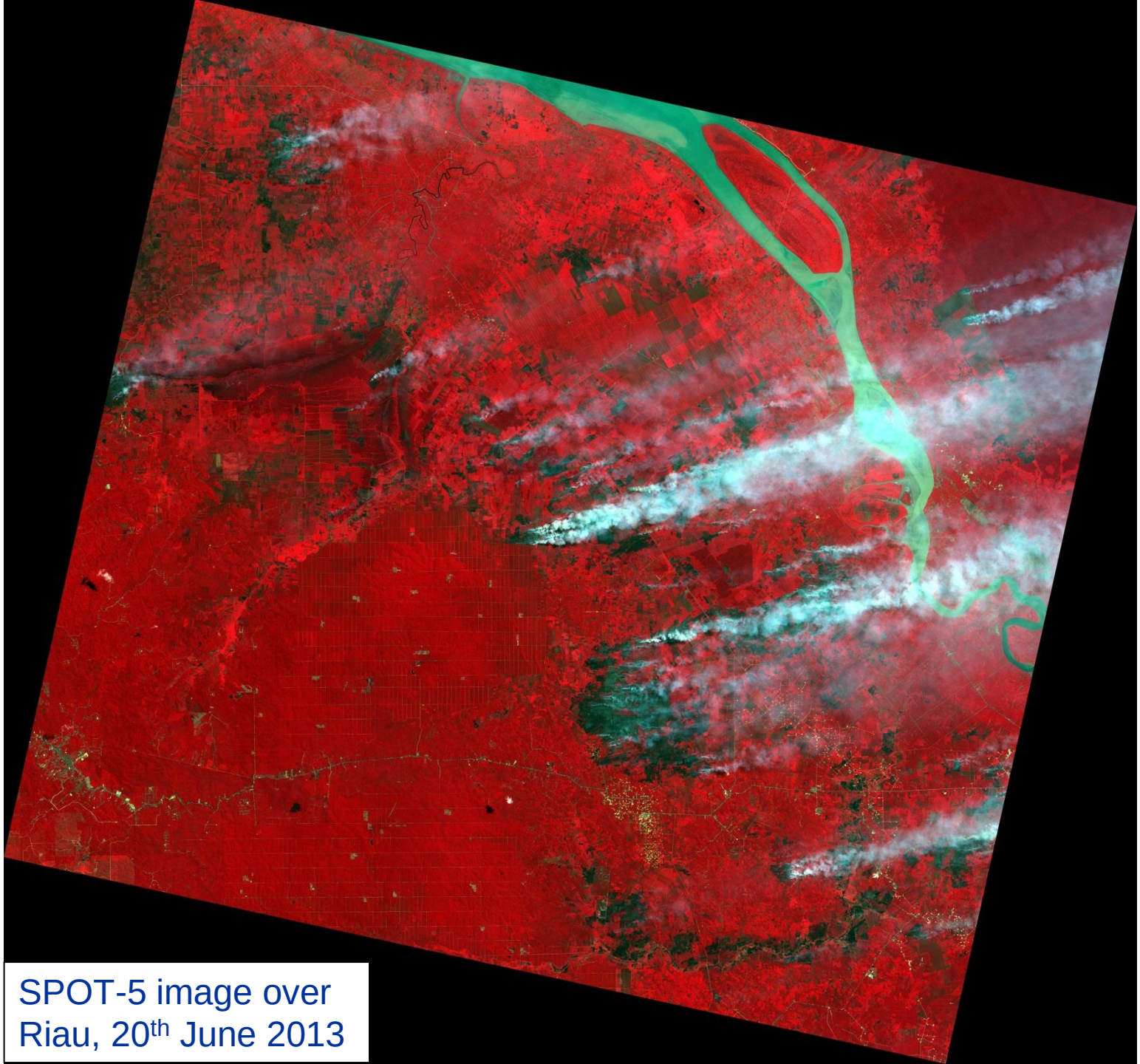
SPOT 7 image in South Sumatra 20th October 2015



2013 June Haze Event

- Did you know that the highest recorded 3-hr PSI in Singapore was in June 2013?
- It was an unusual off-season (June) fire event, occurring during a neutral ENSO phase (neither El Niño nor La Niña).
- During a short episode of very dry weather in Riau, Sumatra, many fires started burning throughout the province.
- At the same time, strong winds blew the smoke from the fires directly towards Singapore.

Terra MODIS true colour image, 20th Jun 2013; hotspots marked out in orange



SPOT-5 image over
Riau, 20th June 2013

June 2013 Haze Event

- The southern half of Peninsular Malaysia, as well as Singapore, was badly affected by the smoke from these fires in Riau.
- In Singapore, the 3-hr PSI hit an all-time record of 401 on 21st June.

3-hour PSI readings in June 2013

Based on PM10 concentration only.[132]

Date/Time	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm
17	N/A	N/A	N/A	N/A	N/A	N/A	N/A	56	56	55	57	64	80	95	100	105	111	110	111	117	140	152	155	150
18	145	N/A	N/A	N/A	N/A	N/A	109	106	108	115	121	123	114	104	95	90	85	81	82	88	97	108	122	133
19	134	N/A	N/A	N/A	N/A	N/A	77	78	80	84	91	103	124	152	170	172	158	146	144	161	190	290	321	282
20	218	195	N/A	N/A	N/A	N/A	137	128	122	131	153	198	299	371	355	312	253	268	310	292	231	197	231	250
21	210	173	143	119	104	96	94	111	158	256	367	400	401	360	245	168	145	143	139	135	137	142	153	168
22	180	183	180	179	177	180	190	231	292	323	326	322	319	263	178	122	85	73	73	77	82	87	90	91
23	91	90	88	89	93	99	104	106	105	101	96	90	83	80	78	78	77	77	76	75	75	76	79	80
24	76	70	64	59	54	51	48	47	47	47	49	52	54	59	65	72	79	82	79	75	72	68	65	61

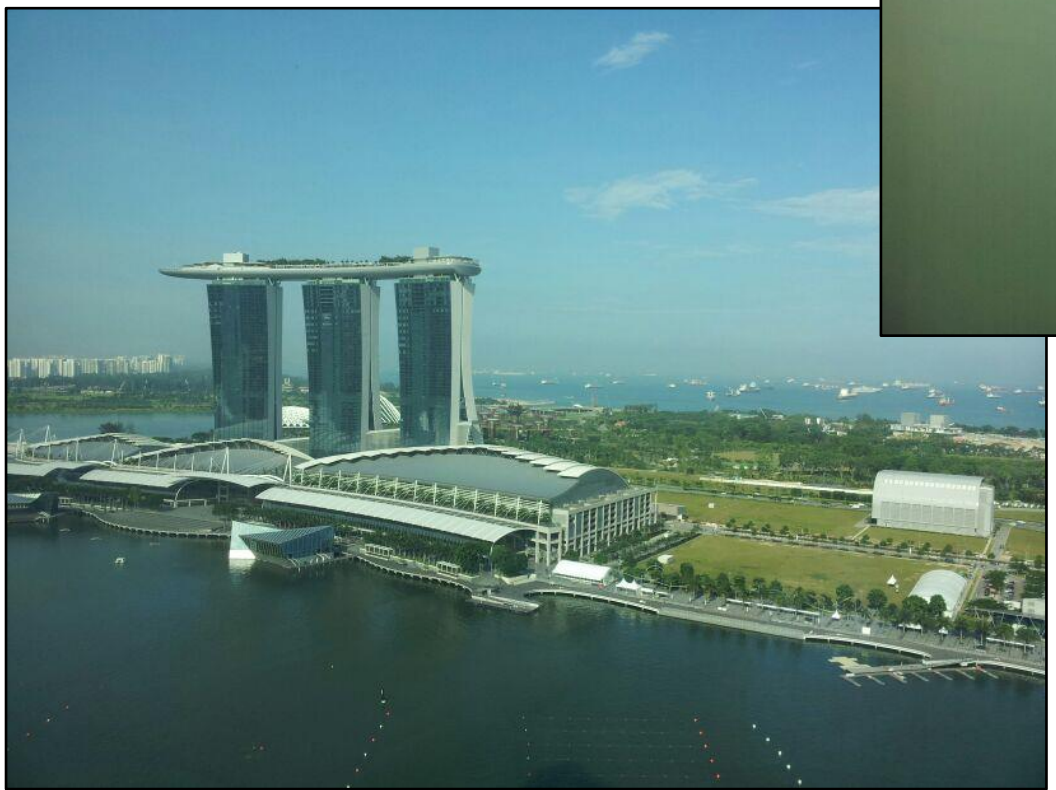
0–50 Good 51–100 Moderate 101–200 Unhealthy 201–300 Very unhealthy >301 Hazardous

3-hr PSI readings recorded in Wikipedia
(https://en.wikipedia.org/wiki/2013_Southeast_Asian_haze)

Singapore, Marina Bay area

Haze, around noon, 21st June 2013

Normal, sunny day



Thank you for your attention

S2S building, with rooftop antenna