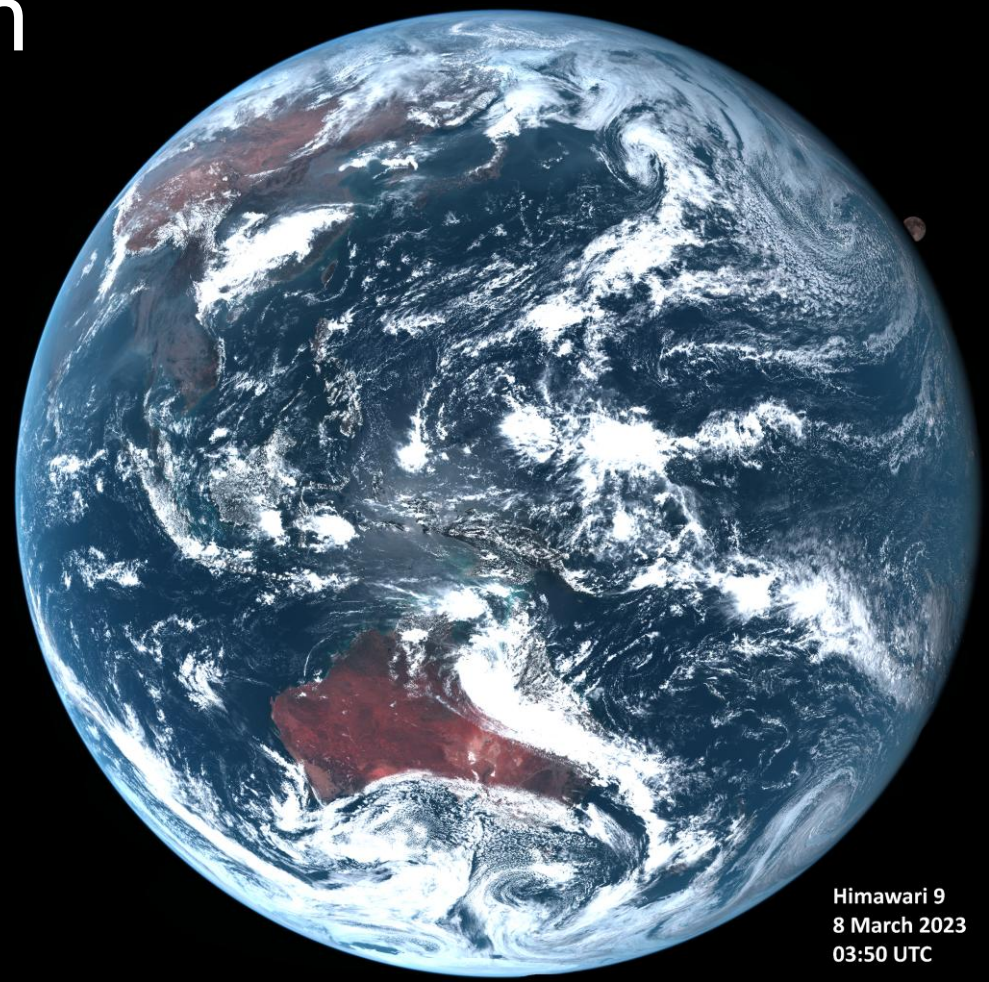
High-Resolution Landscape Fire Monitoring: Satellite-Guided Reconstruction Of Ground-Level Air Pollutants at 10-minute and 500 m Scale

Dr Miles Sowden



Himawari captures extraordinary detail
moon, smoke, fire and motion.
The challenge is converting that into
residential-scale air quality, beneath cloud.

Current Models/Data Fail to Address Landscape Fire Challenges

- AOD large scale smoothing ~ 6 km
- MODIS twice a day
- AOD is not BoD
- Cross-border issue
- Sparse monitoring of limited pollutants
- We need fast systems now
  - Minderoo Fire Shield Mission ONE minute detection

A Black Summer's day (10 Dec 2019 NSW Australia)

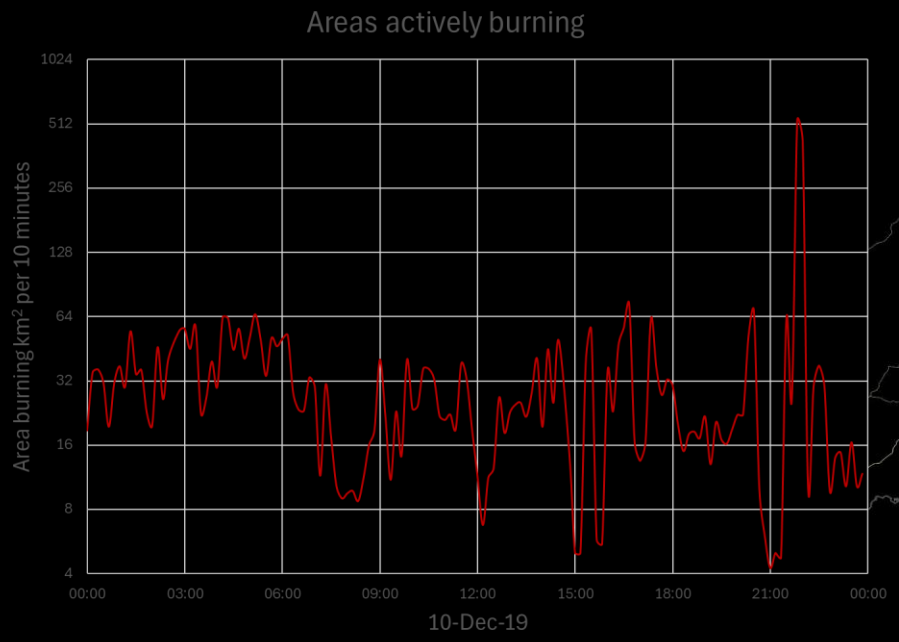
MODIS Fires & Thermal Anomalies (day + night)

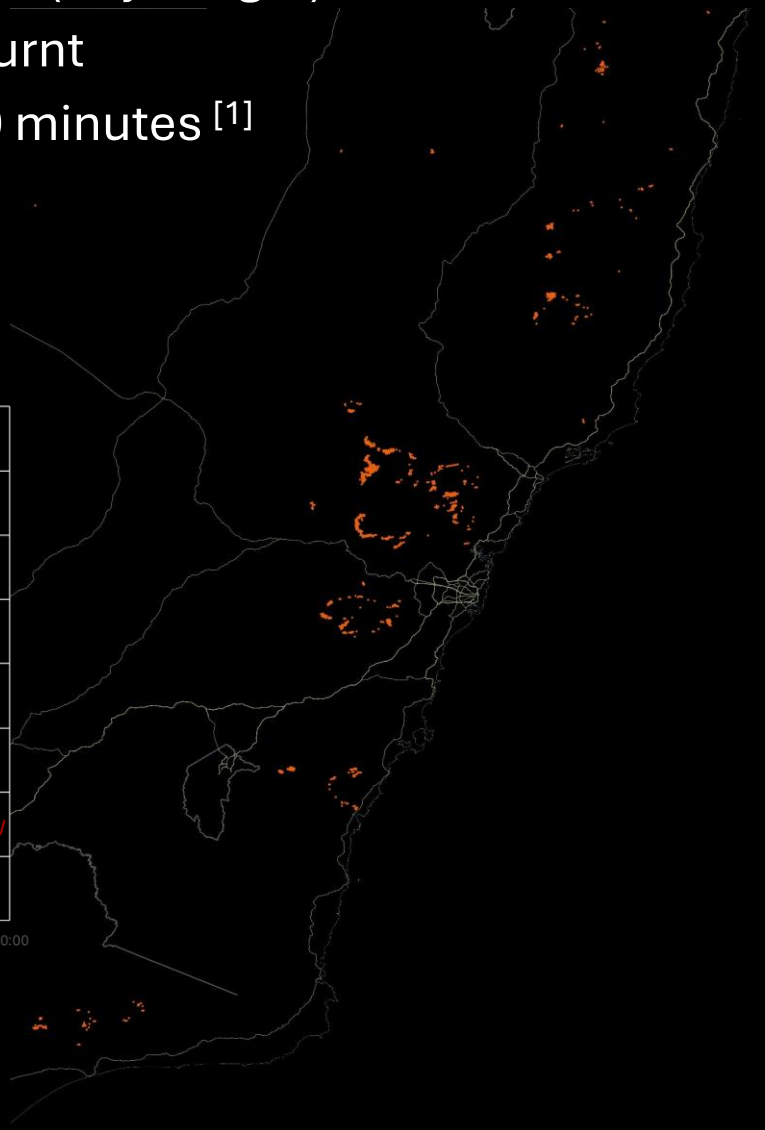
Estimated 5.5 million hectares burnt

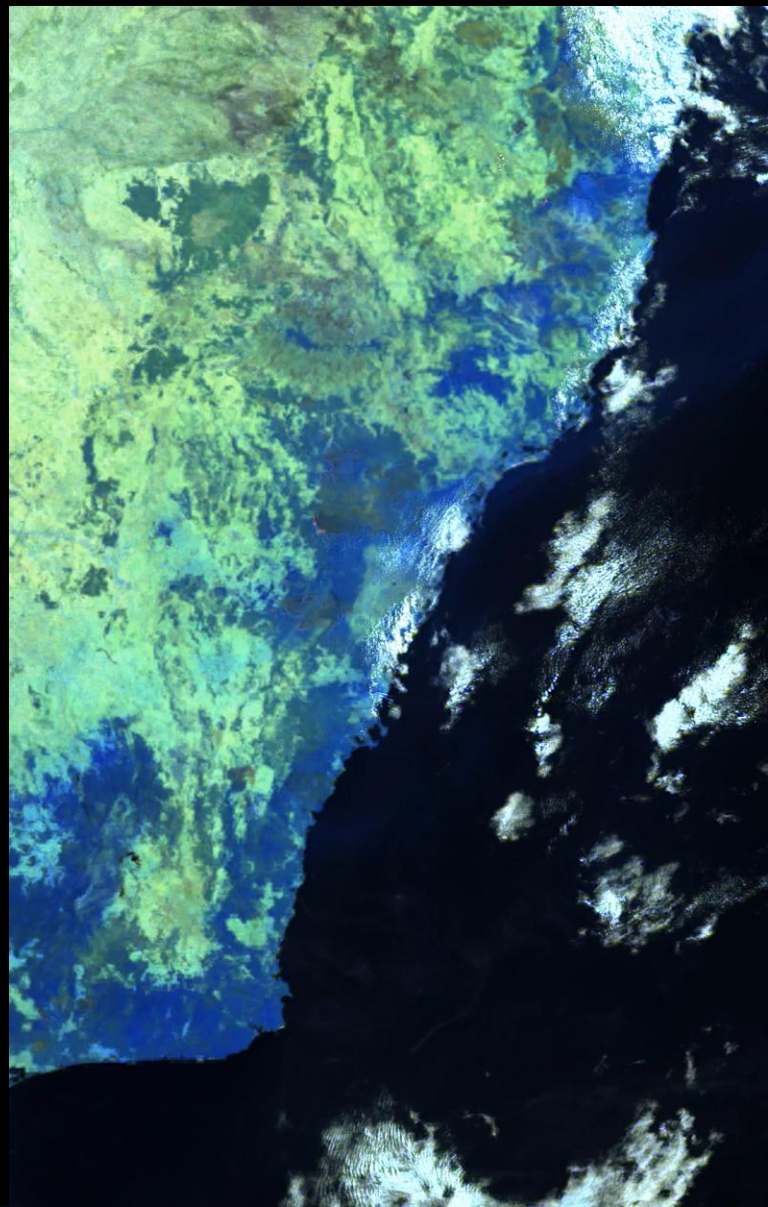
Gospers Mountain ≈ 22 km^2 in 10 minutes [1]

Too fast for modelling

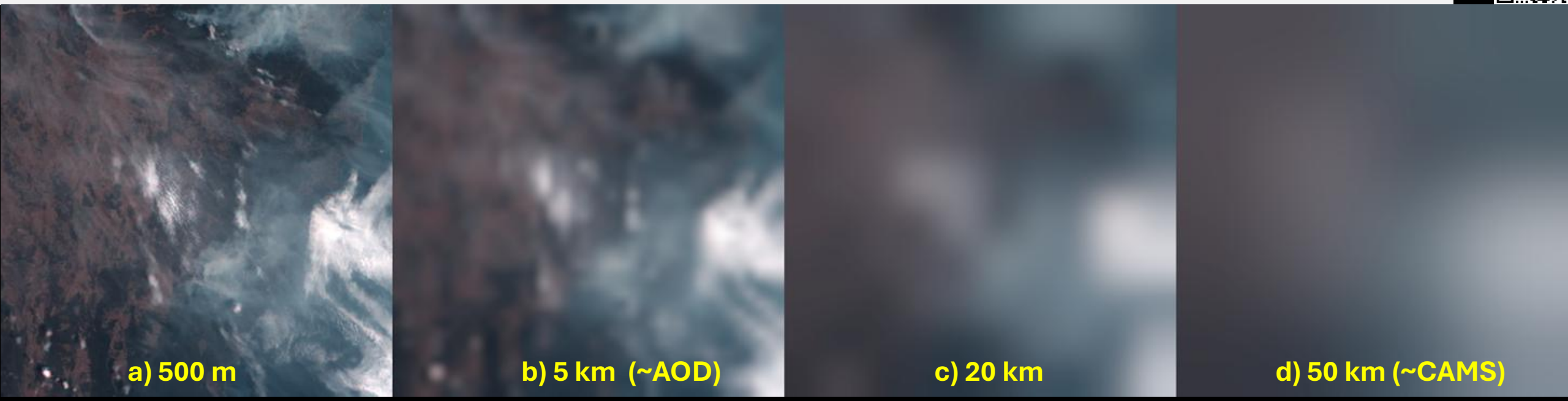
Sparse monitoring



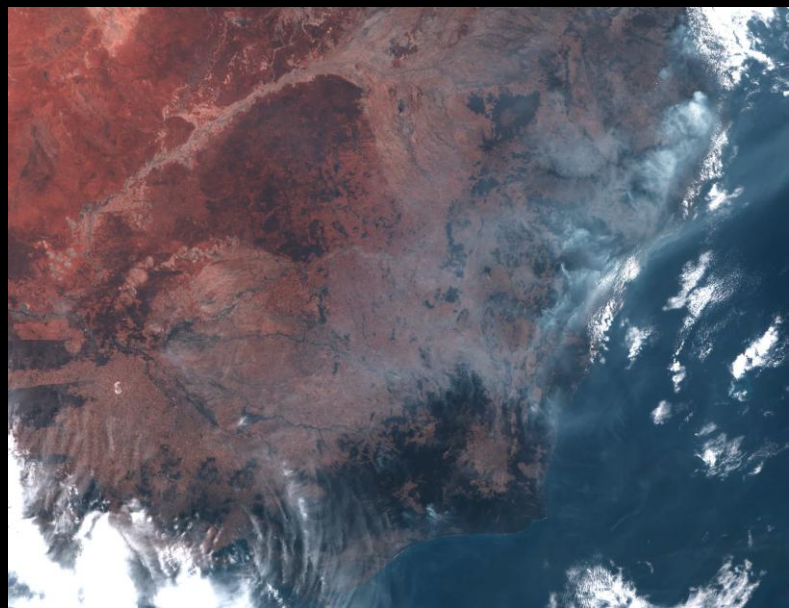




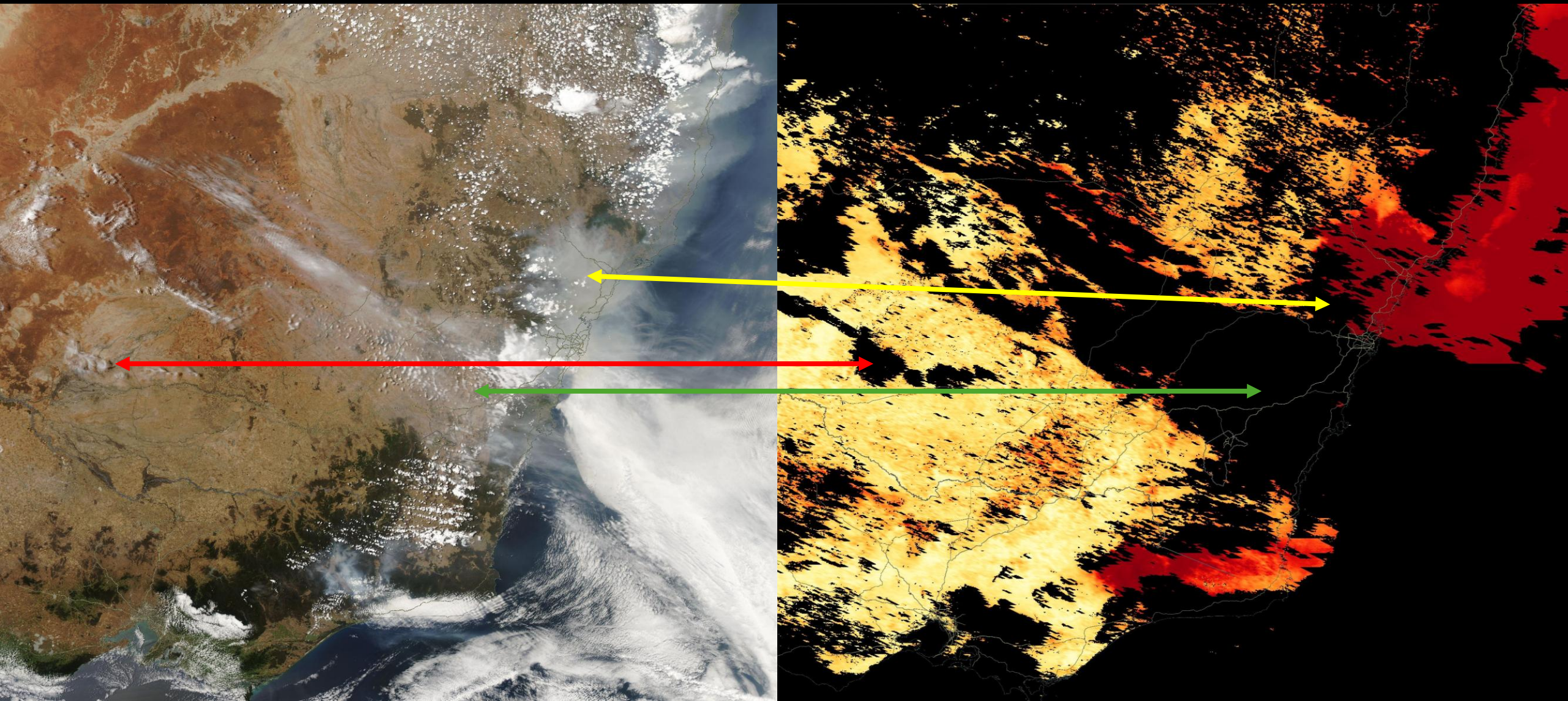
WHERE Visualizing the Resolution Disparity: Why 500m Matters



- High resolution is essential to resolve local health exposure
- Health metrics at postcode scale ≈ pixel
- e.g. Northbridge 1.5 km^2; Redfern 2.4 km^2

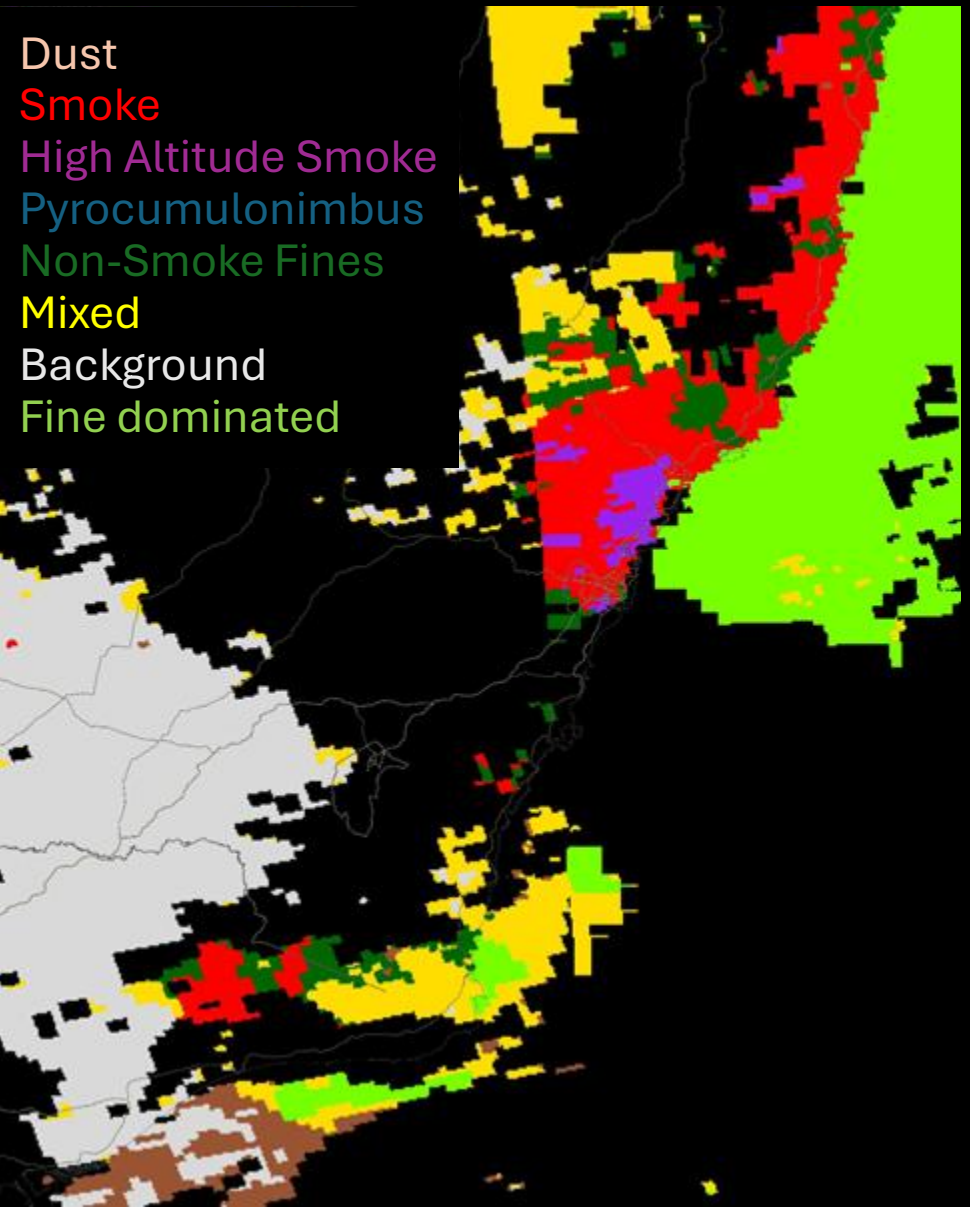


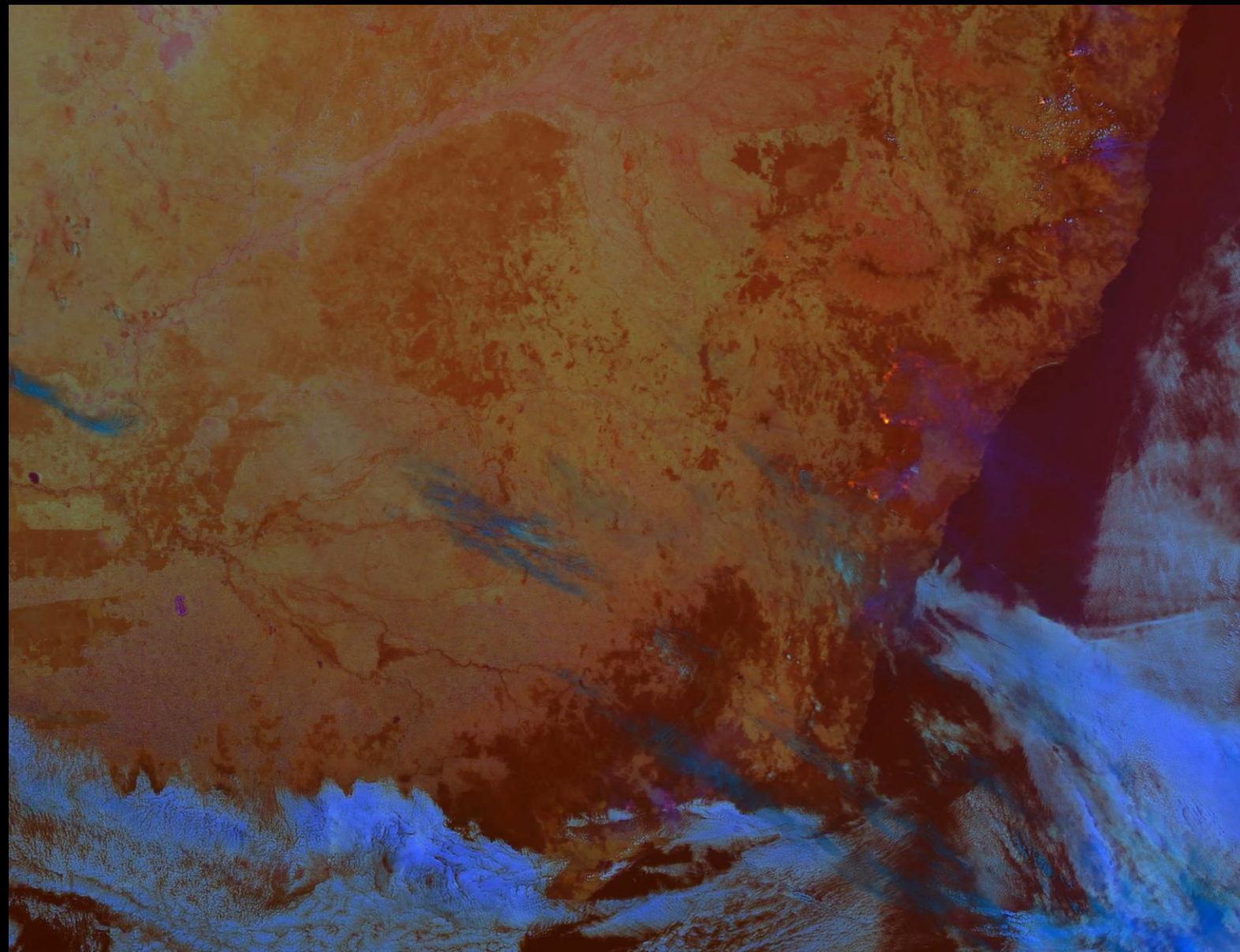
WHERE MAIAC (1km) AOD coarse, cloud gaps and columnar



Overcoming Cloud Gaps and Coarse AOD Speciation

Deep Blue Aerosol Type (6km) vs Himawari classification





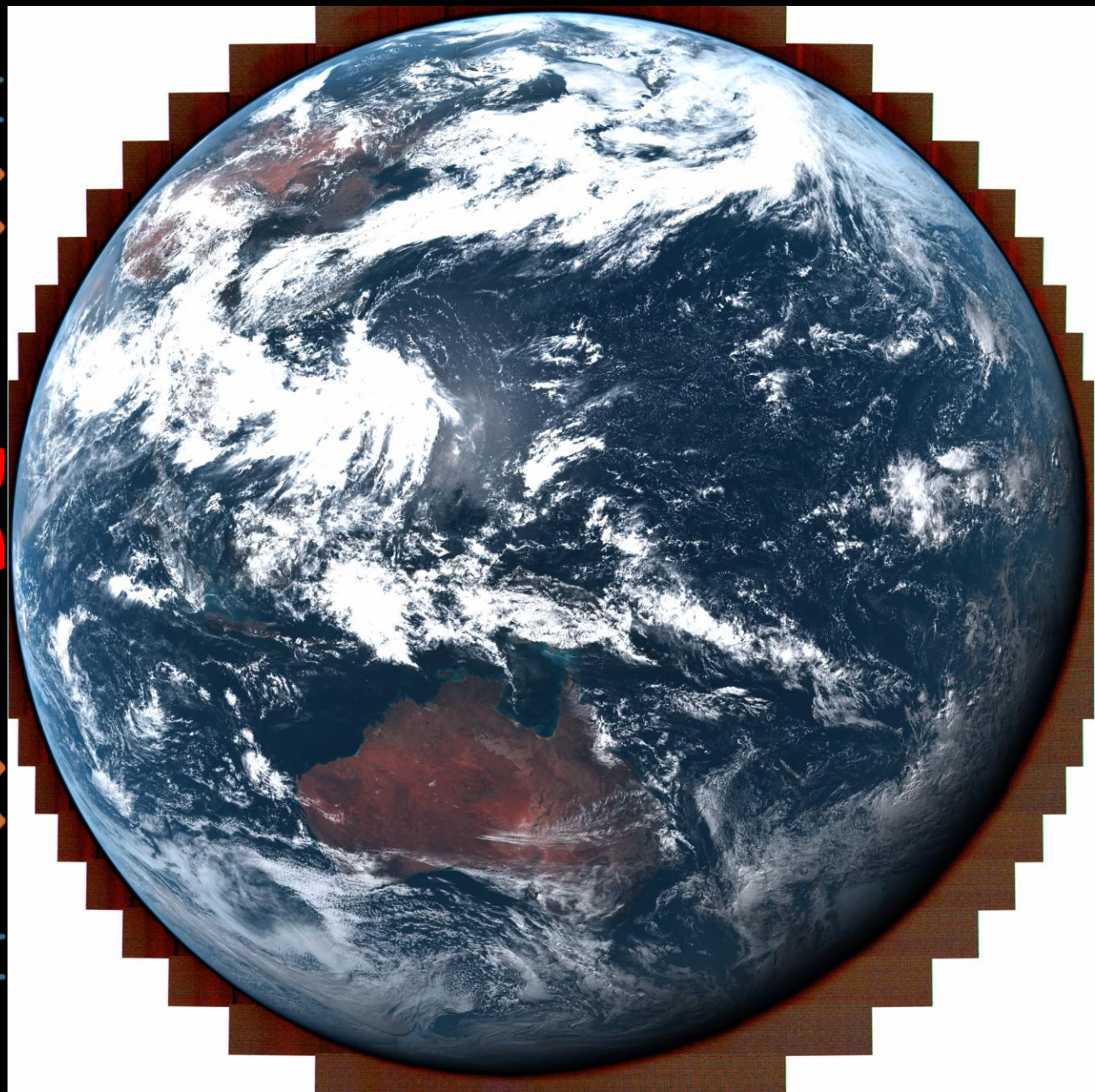
Why Run Forecasting (WRF) = Lorenz Energy Cycle (LEC)

- **Energy build-up**
  - Heat builds gradients → climate-change driver
  - Potential Energy (∂x, ∂y, ∂T) → motion → KE
  - Hadley / Ferrel / Polar cells = global circulation
  - El Niño: Smaller Hadley, trade winds weaken, warm water east, drought/fire in Australia
  - La Niña: Hadley cell increase, trade winds strengthen, warm water west, more floods

- **Energy conversion**
  - KE components: U, V, W
  - Eddies form at cell boundaries (σθ → chaos)
  - Rotational energy = ½ mv^2 ($\partial^2x/\partial t^2$)
  - Flow consumes energy → D(KE)
  - Friction dissipates

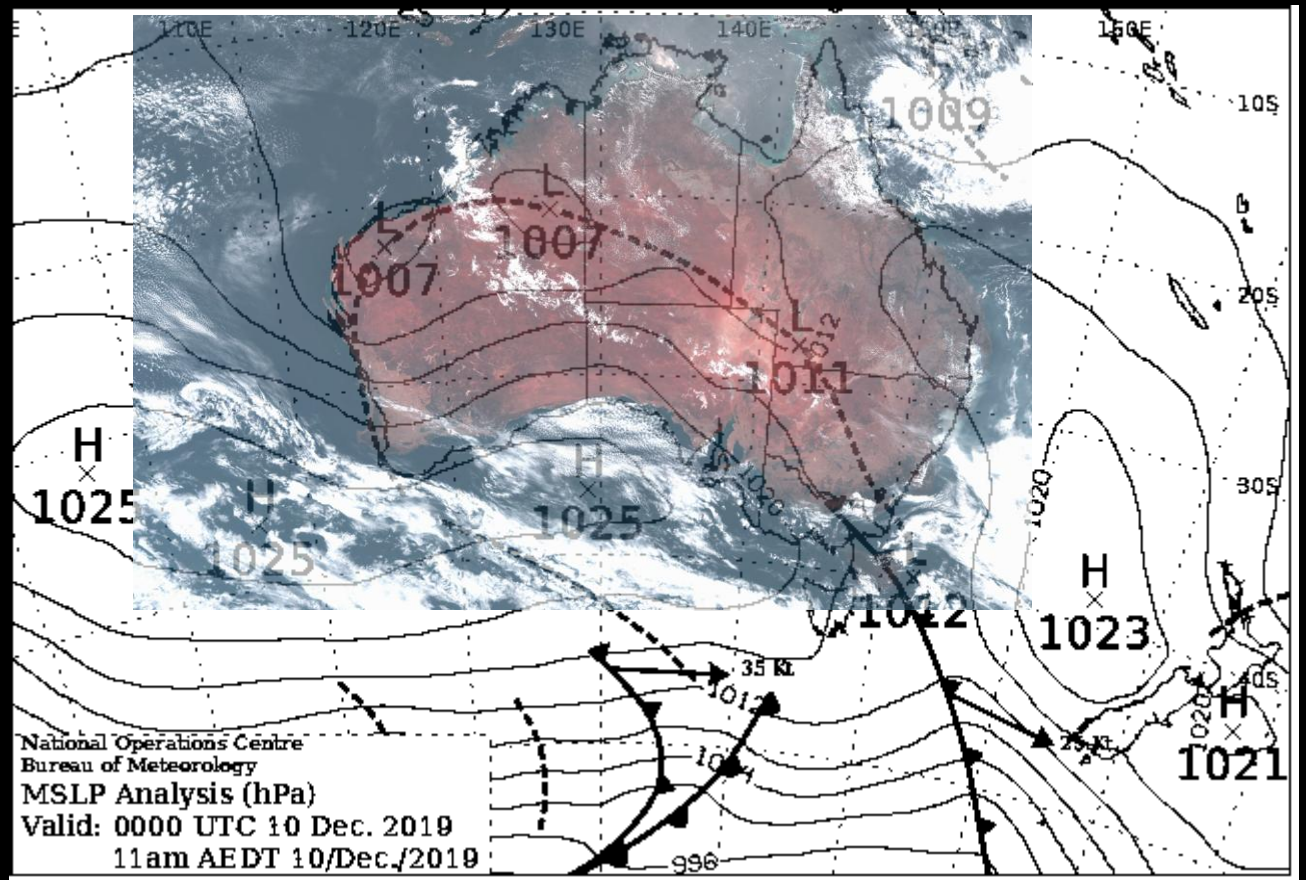
- **Energy limits**
  - LEC transfer = chaotic flow → butterfly effect
  - Forecast skill ≈ 4–14 days

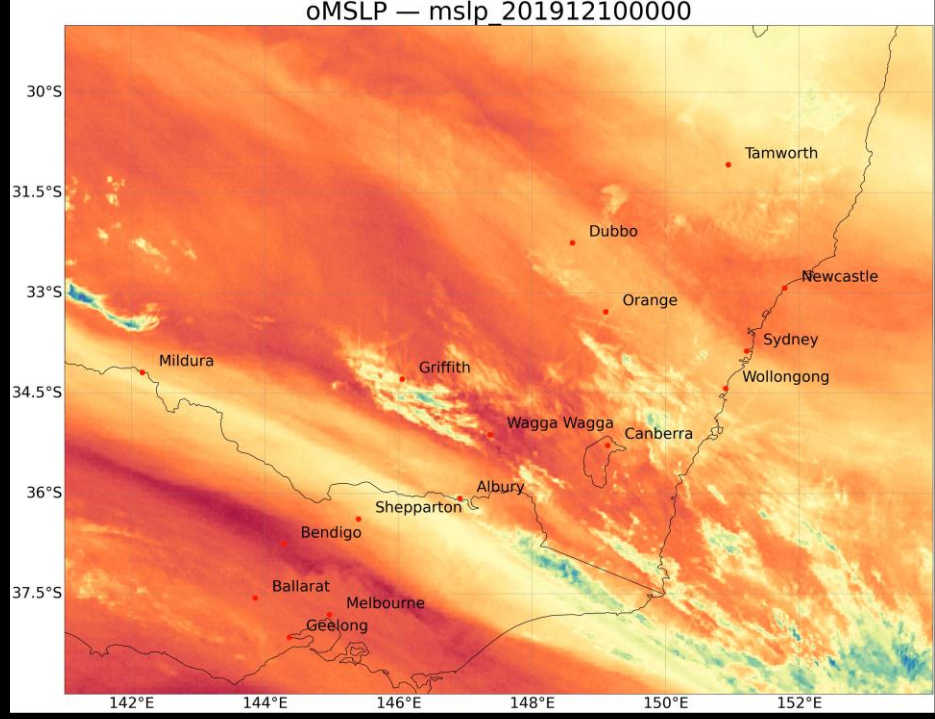
Himawari observes these transitions in real time, the perfect analogue computer.
Don't model what we can already measure!!!

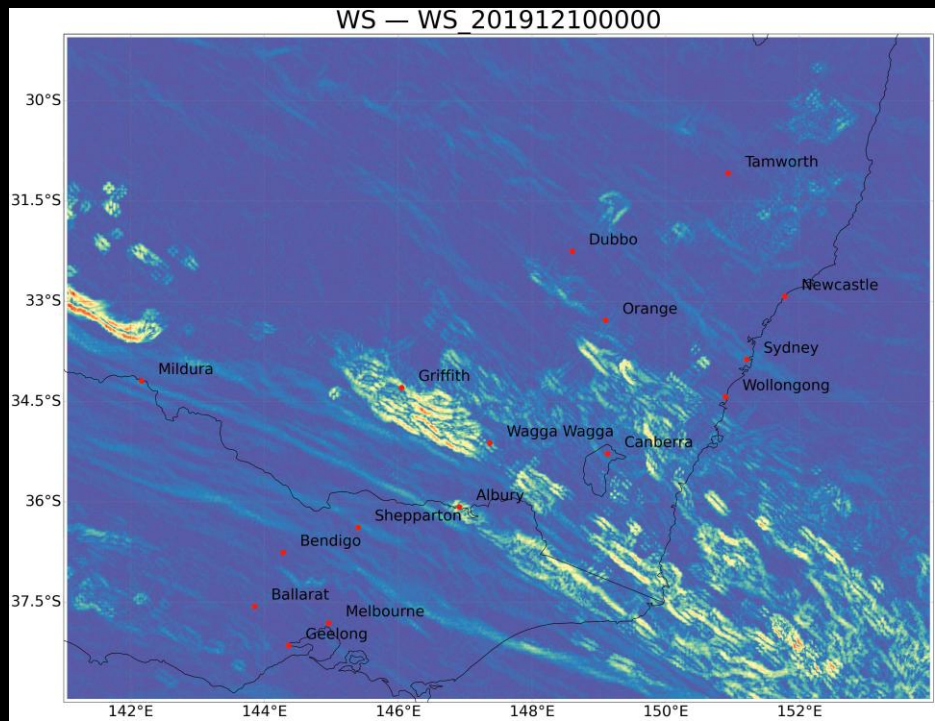


What Himawari Captures (WHC)

- The atmosphere computes in massive parallel—like a GPU, not a CPU
- Himawari captures the real-time output of this natural computation
  - MSLP derived from $BTD_{10–09}$ captured synoptic trough and cold front
  - U, V from ∇MSLP = ∇ pressure: Not LEC and EOM they are outputs
  - WHC drives plume dispersion, fans fires and lifts-off dust
- Geminid meteor shower (https://www.abc.net.au/news/science/2019-12-11/meteor-shower-geminids-2019/11783918)





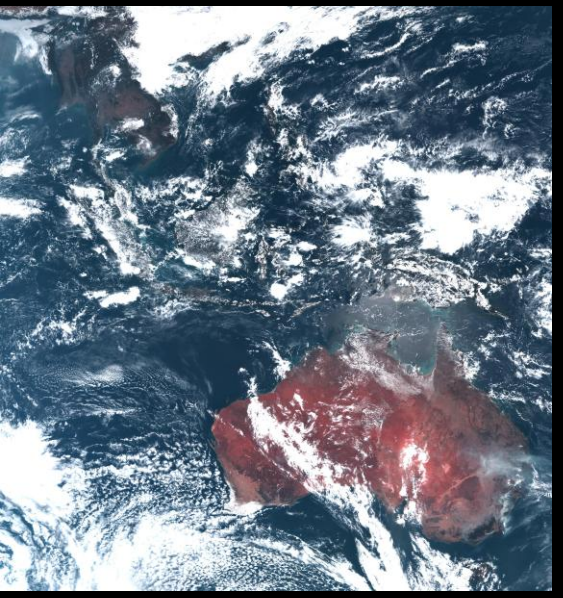


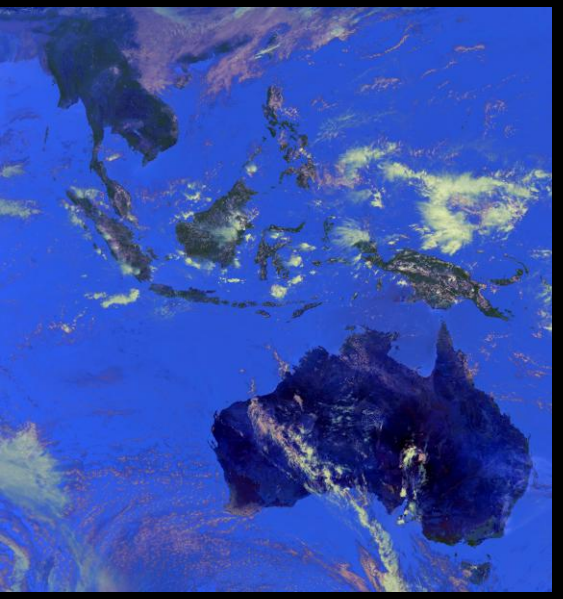
WHAT is needed to assess BoD (CAMS Reanalysis ECMWF 2024)

8 Criteria Pollutants	11 Aerosol Species (µg/kg)
CO ppmv	SS-F01 Sea Salt Aerosol (0.03 - 0.5 um)
O_3 ppmv	SS-M02 Sea Salt Aerosol (0.5 - 5 um)
NO ppmv	SS-C03 Sea Salt Aerosol (5 - 20 um)
NO_2 ppmv	DU-F04 Dust Aerosol (0.03 - 0.55 um)
SO_2 ppmv	DU-M05 Dust Aerosol (0.55 - 0.9 um)
PM_1 µg/m^3	DU-C06 Dust Aerosol (0.9 - 20 um)
$PM_{2.5}$ µg/m^3	OC-W07 Hydrophilic Organic Matter Aerosol
PM_{10} µg/m^3	OC-H08 Hydrophobic Organic Matter Aerosol
C_5H_8 Isoprene ppmv	BC-W09 Hydrophilic Black Carbon Aerosol
	BC-H10 Hydrophobic Black Carbon Aerosol
	SUL-11 Sulphate Aerosol

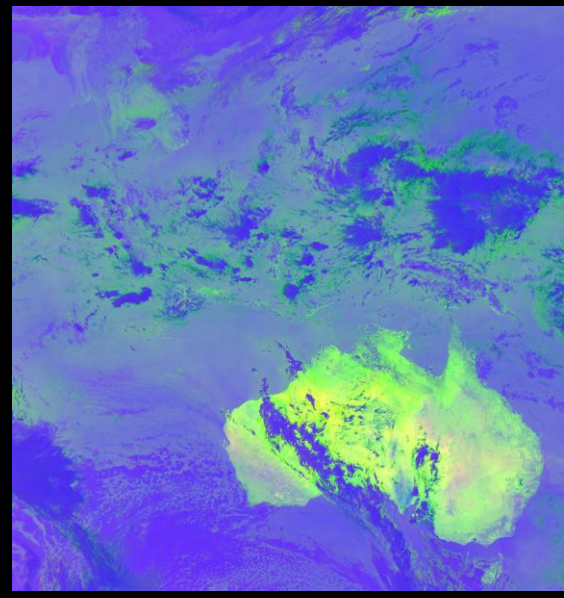
CAMS (coarse) and Monitoring (sparse, few pollutants, no aerosol speciation)

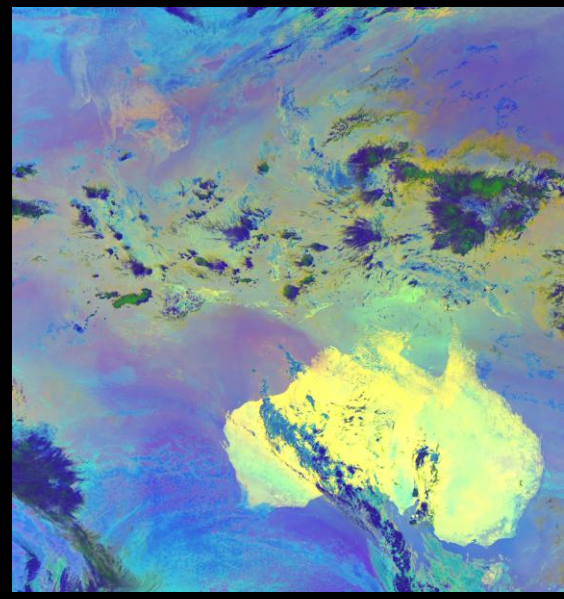
WHAT can we extract from Himawari data (Schmidt et.al 2018)





Band	Wavelength	Application
1	0.471	vegetation, aerosol
2	0.51	vegetation, aerosol
3	0.639	low cloud, fog
4	0.857	vegetation, aerosol
5	1.61	cloud phase
6	2.257	particle size
7	3.885	low cloud, fog, forest fire
8	6.243	mid and upper-level moisture
9	6.941	mid-level moisture
10	7.347	mid and low-level moisture
11	8.593	cloud phase, SO_2
12	9.637	ozone content
13	10.407	cloud top, “clean longwave window”
14	11.24	cloud, SST
15	12.381	cloud, SST, “dirty longwave window”
16	13.281	cloud top, CO_2

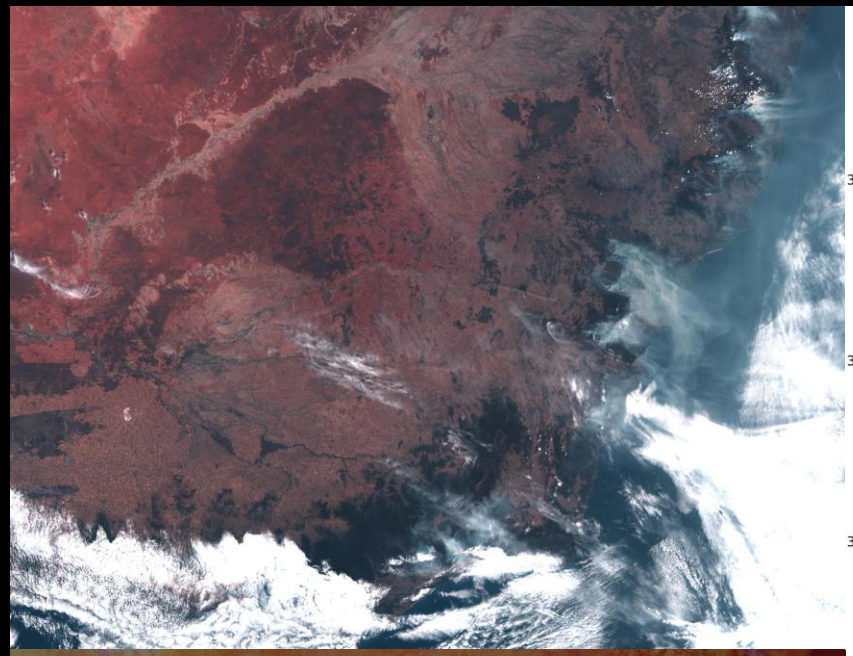


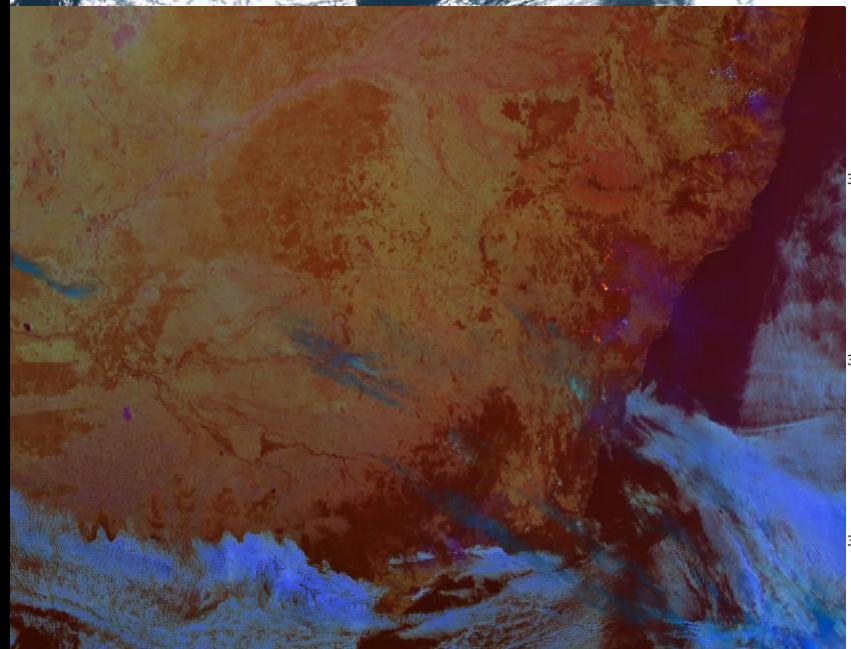


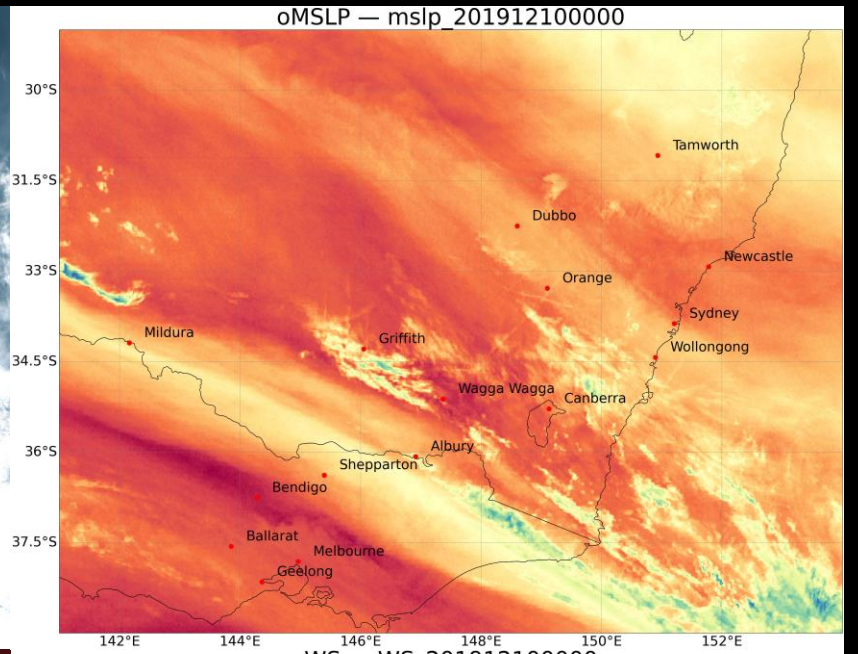
WHEN Spectral Physics: Our Engine for Pollutant Speciation

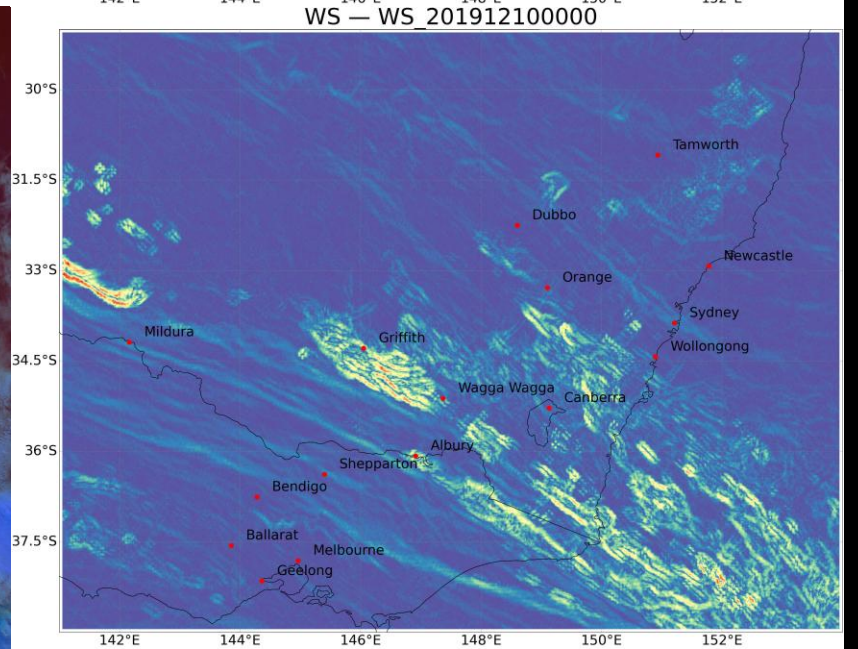
- BTD = H_2O, species & PM size
- Composite Visuals
  - $TRUE_{321}$, $SWIR_{654}$
  - GAS $_{BT07–08, BT14–15, BT12–16]}$
  - AER $_{BT13–11, BT14–15, BT12–16}$

  https://www.jma.go.jp/jma/jma-eng/satellite/VLab/RGB_QG.html
- BTD data rich
  - BTD_{0708} Fire hotspots/low RH
  - BTD_{1009} Vertical stability (LEC)
  - BTD_{1415} Particle size
  - BTD_{1311} Aerosol vs Gas
  - BTD_{1216} Gas (O_3 vs CO_2)
- HOW
  - Air Type = f(BTD_{ij},$Radiance_k$)
  - Conc ∝ MSLP & WS
  - Calibrate against CAMS



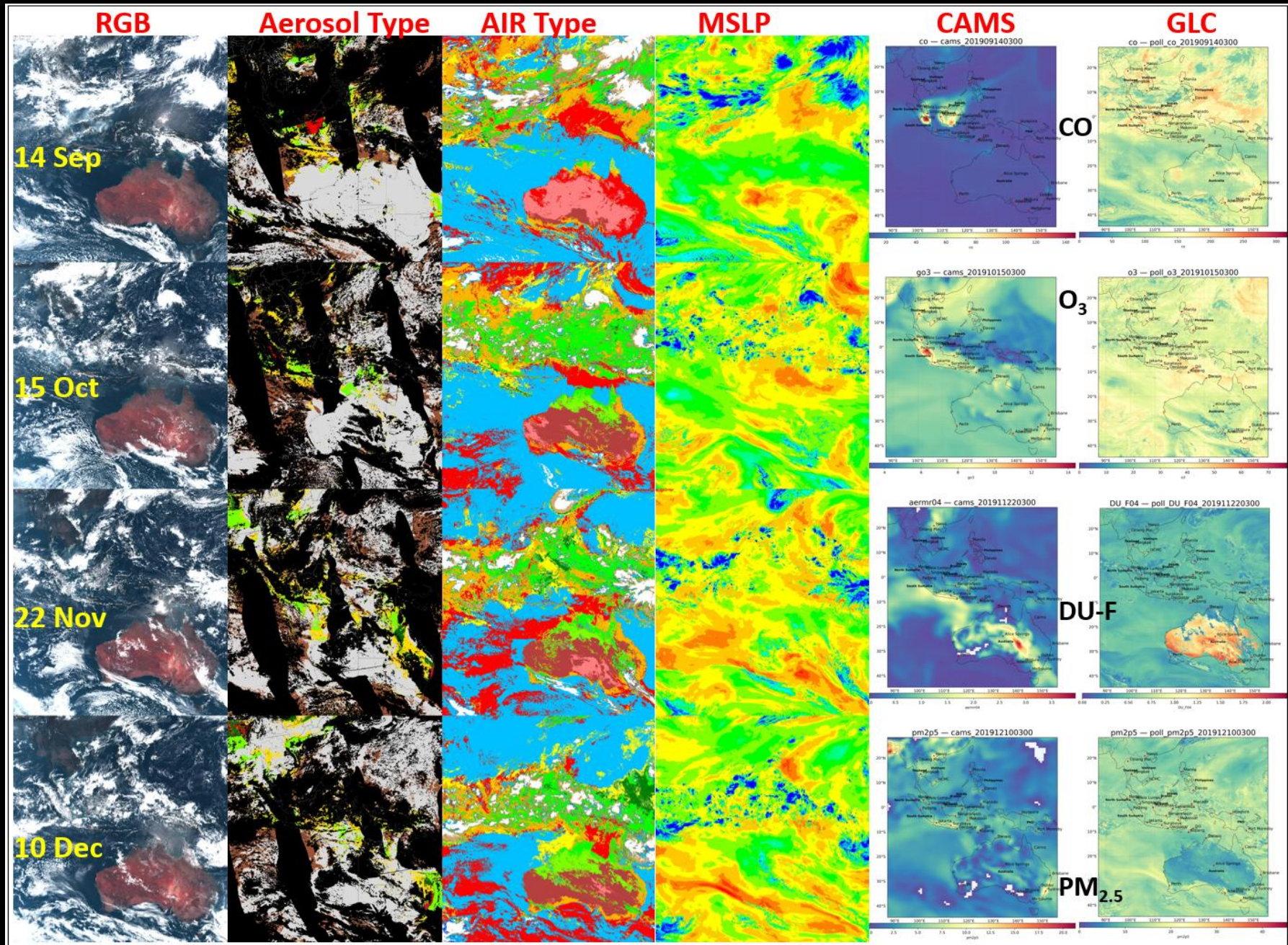




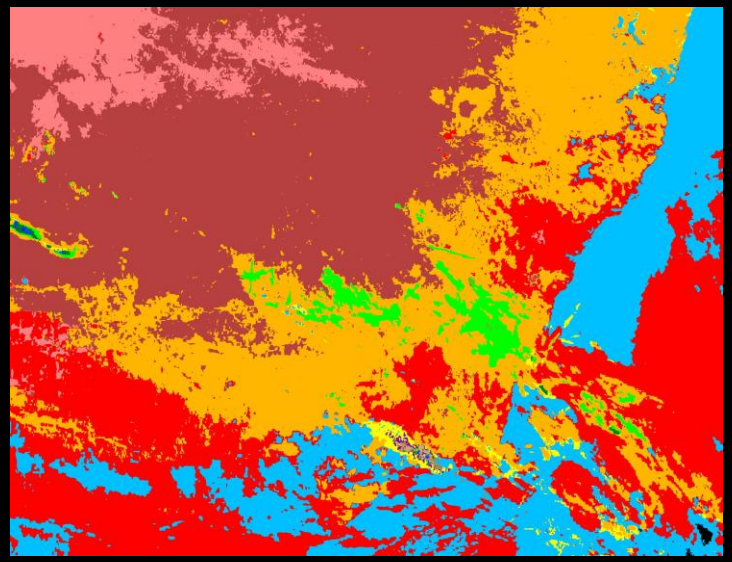


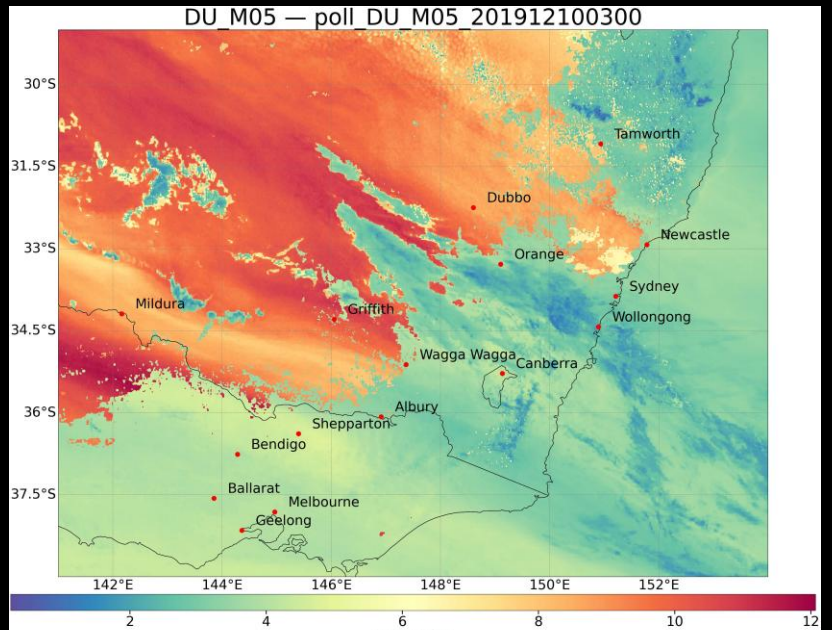
Analysis of High-Impact Pollution Events Across Australasia (2019)

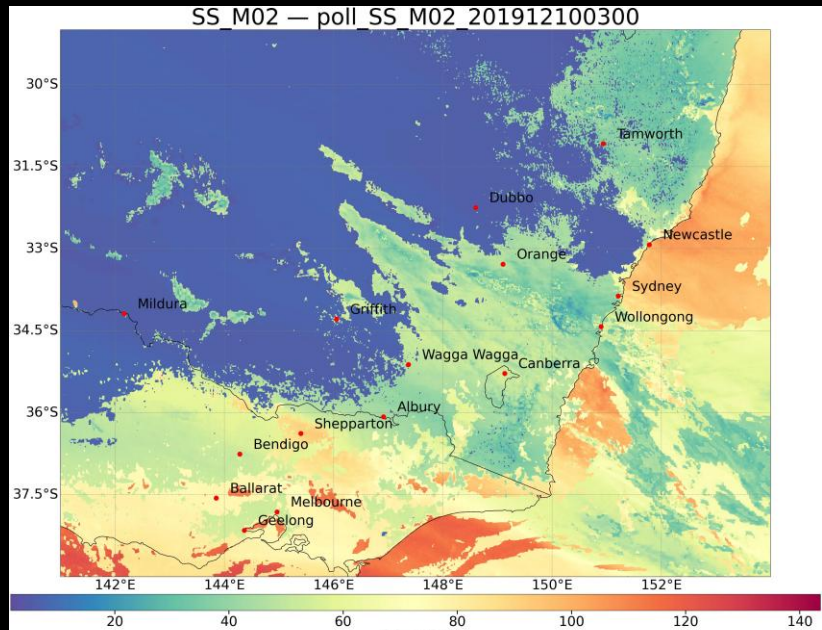
- Four events – Kalimantan, Hanoi, NSW, Black Summer
- RGB, MODIS, Air Type, MSLP, CAMS & GLC
- Cloud gaps minimal with IR
- Mixed dust–smoke–gas plumes resolved
- CAMS coarse ~75 km Himawari resolves 500 m
- BTD enables Air Type and GLC estimation
- Validation and development ongoing
- 500m / 10-min resolution maps acute exposure

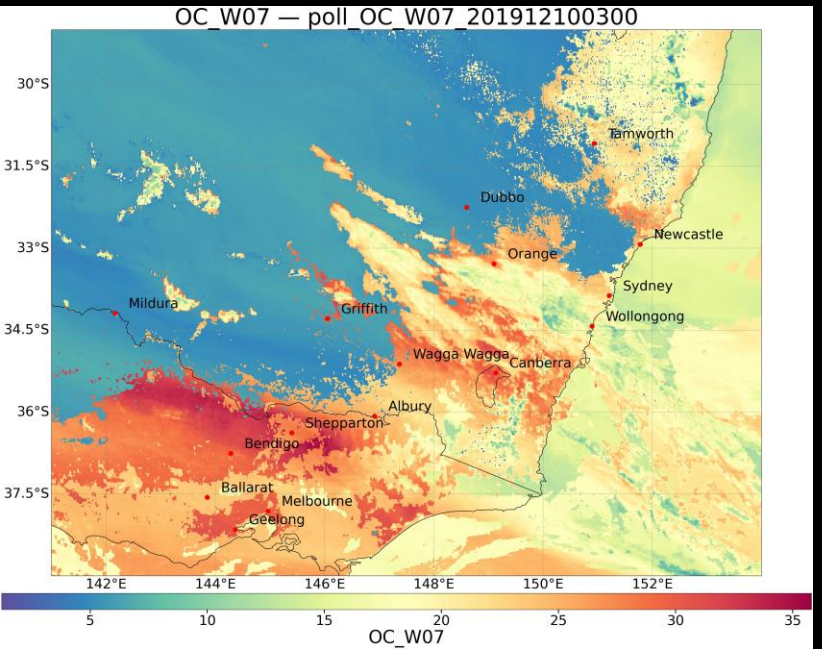


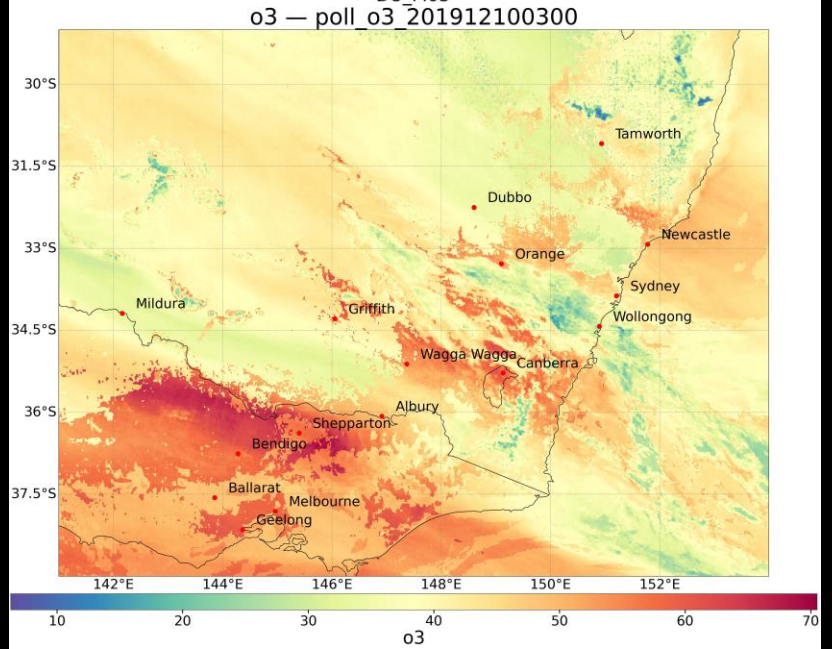
NSW Fires – Multi-Species Retrievals Under Partial Cloud

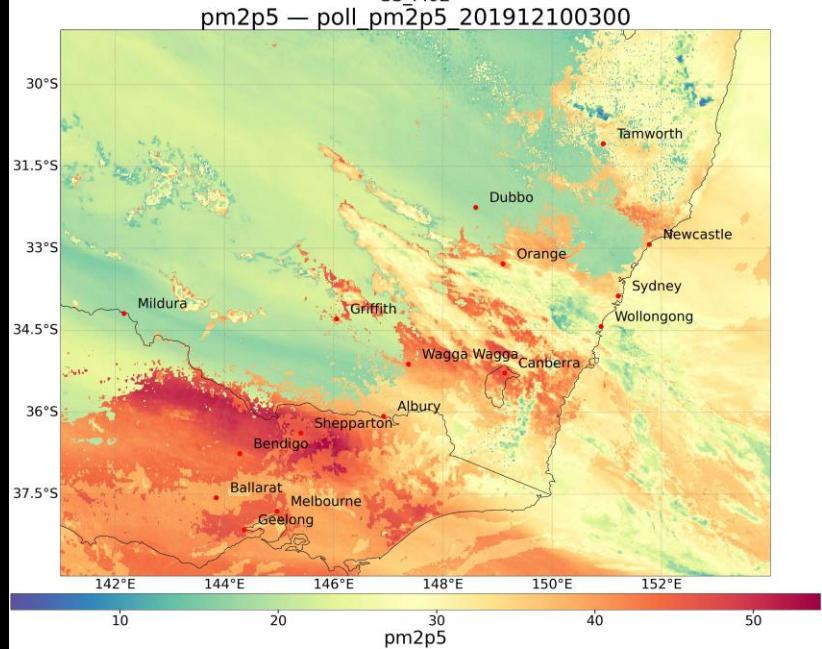












ΔFusion demonstrates:

- ✓ The atmosphere = massive GPU analogue computer (not CPU)
- ✓ Ten-minute, 500 m resolution of the physics (WS, inversion)
- ✓ 16 bands, don’t overlook or re-model data
- ✓ Solve BoD not AOD
- ✓ Cloud, what cloud?
- ✓ Classify by air type (smoke, dust etc) not individual species
- ✓ Smoke strongest in B03, dust B06 & thermal channels

Future Directions

- Fuse air dispersion into retrieval methodology
- Leverage time differences: $Conc_t = Conc_{t-1} + dC/dt$
- Treat hemispheres separately: N=cloud/haze vs S=desert dust
- CAMS too coarse, Local validation essential
  - NSW: accessible, local, dust
  - Asia: transboundary, haze, cloud
- Near–Real-Time (NRT) GLC estimation via API

General Applications

- Smoke reconstruction
- Dust/smoke transport
- Visibility analysis
- Rapid-changing plumes
- Inversion detection
- Fire-behaviour diagnostics
- Exposure/BoD analysis
- Model validation

Mining Applications

- Lightning shutdown alerts
- Dust uplift warnings
- Blast inversion checks
- Haul-road visibility
- Heat-load hotspots
- Smoke/dust events
- Rapid exceedance verification
- Adverse weather conditions

Why This Matters

- Better exposure science - 10-year dataset + nowcasting
  - 10-min / 500 m exposure
  - Short PM spikes captured
  - Plume timing = impact
- Better health assessment
  - BoD needs intensity + duration
  - Full BT, radiance and BTD's, not AOD smoothing
  - Scalable national datasets
- Better decisions
  - Earlier warnings (smoke, hospital surge)
  - Protect vulnerable groups
  - Support emergency response

References

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