Headquarters
New Zealand Defence Force
Defence House
Private Bag 39997
Wellington Mail Centre
Lower Hutt 5045
New Zealand

OIA-2023-4649

28 March 2023

[redacted]
[redacted]gmail.com

Dear [redacted]

I refer to your email of 28 February 2023 requesting, under the Official Information Act 1982 (OIA), the following:

> *Under the Official Information Act, I request any information held by your agency regarding the study and utilization of Directed Energy Weapons (D.E.W) in New Zealand. Specifically, I would like to know:*
> *Whether the New Zealand government or any of its agencies, departments, or branches have studied or conducted research on Directed Energy Weapons.*
> *Whether Directed Energy Weapons are currently being utilized by the New Zealand Defense Force or any other government agency in any capacity.*
> *Whether there are any plans or proposals to utilize Directed Energy Weapons in New Zealand in the future, and if so, what are the details of these plans.*
> *Whether there are any laws, regulations, or guidelines in place that govern the use of Directed Energy Weapons in New Zealand.*
> *Please provide any documents, reports, contracts, or other information that can shed light on the above questions. If any information is classified or sensitive, please let me know and provide a reason for why it cannot be released.*

In 2017, the New Zealand Defence Force (NZDF) gathered information for a Directed Energy Weapons (DEW) workshop for the Royal New Zealand Navy's Future Surface Combatant Project. The information on high-energy lasers was gathered from open source literature and did not present any novel research. The workshop covered the history of high-energy laser development, the principles of operation, and atmospheric effects. The Navy project was discontinued, and the NZDF has no plans to undertake further research or utilise DEWs.

Two presentations prepared for the workshop are enclosed. The names of the presenters are withheld in accordance with section 9(2)(g)(i) of the OIA. The name and contact details for a NASA staff member are also withheld to protect privacy in accordance with section 9(2)(a) of the OIA.

The Navy currently uses the Long-Range Acoustic Device (LRAD) system on some of its ships. This non-lethal loudhailer and warning system is typically used by police and military forces. Further detail on the LRAD is withheld in accordance with section 6(a) of the OIA.

New Zealand has ratified the United Nations Convention on Certain Conventional Weapons (CCW). The CCW applies only to the military use of laser weapons in armed conflicts.

Limitations on the use of DEWs by police and military forces within New Zealand's borders are the subject of national laws.

You have the right, under section 28(3) of the OIA, to ask an Ombudsman to review this response to your request. Information about how to make a complaint is available at www.ombudsman.parliament.nz or freephone 0800 802 602.

Please note that responses to official information requests are proactively released where possible. This response to your request will be published shortly on the NZDF website, with your personal information removed.

Yours sincerely

AJ WOODS
Air Commodore
Chief of Staff HQNZDF

Enclosures:
1. Short History of Directed Energy Weapons presentation
2. Is the Environment the Ultimate Jammer? presentation

A Short History of Directed Energy Weapons

Presentation for DEW forum
8 Nov, 2017

s9(2)(g)(i)
C4ISR Systems Group
Defence Technology Agency

Outline

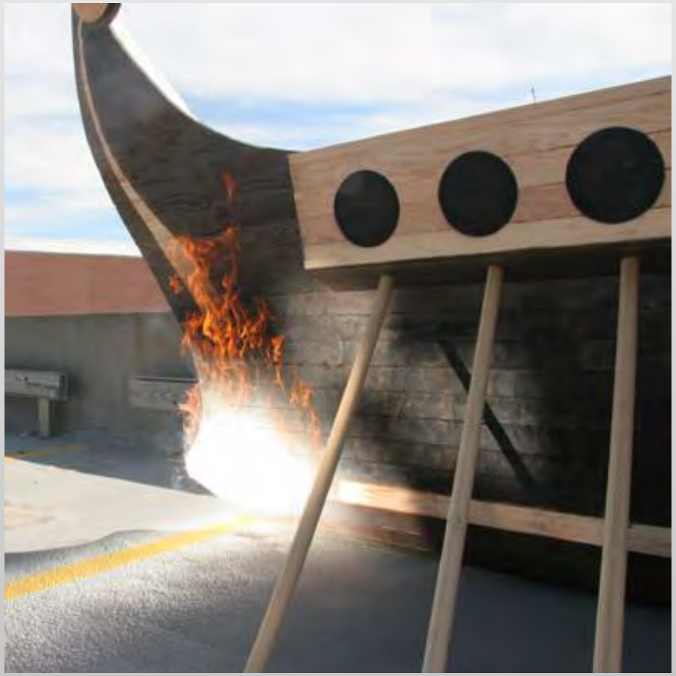
- Legal constraints on laser weapons
- Airborne Laser Laboratory
- Scintillation
- Boeing Airborne Laser Project
- High Power Fibre Lasers
- US Navy Laser Weapon System
- Lockheed Martin, MBDA systems
- Countermeasures
- Conclusions

The first Directed Energy Weapon?

- Legend of Archimedes' burning mirror
- Siege of Syracuse, 212 BC
- Allegedly, an array of mirrors were used to burn Roman ships
  - *"…The rays being reflected by this, a frightful fiery kindling was excited on the ships, and it reduced them to ashes, from the distance of a bow shot. Thus the old man baffled Marcellus, by means of his inventions"*

Attempted recreations...

- 1973 Greece
  - 60 x 15 square-foot mirrors
  - Ignited wooden ship 160 ft away "within seconds"
- 2009 MIT
  - 127 x 1 square-foot mirrors
  - Oak ship starts burning after 10 minutes of exposure
- 2010 Mythbusters
  - 500 flat mirrors held by students
  - Hard to focus consistently on one spot
  - Could not ignite a sail after 1 hour



Legal Constraints on Laser Weapons

- UN Convention on Certain Conventional Weapons (CCW)
  - Seeks to prohibit or restrict the use of certain conventional weapons which are considered excessively injurious or whose effects are indiscriminate
  - Five protocols
    I. Non-detectable fragments
    II. Mines, booby-traps and other devices
    III. Incendiary weapons
    IV. Blinding Laser Weapons
    V. Explosive Remnants of War
- NZ has ratified the CCW
  - Protocol IV in force from July, 1998
  - NZ Treaty Series 1998, No. 12

Articles of Protocol IV of the UNCCW

- Article 1
  - **It is prohibited to employ laser weapons** specifically designed, as their sole combat function or as one of their combat functions, **to cause permanent blindness to unenhanced vision**, that is to the naked eye or to the eye with corrective eyesight devices. The High Contracting Parties shall not transfer such weapons to any State or non-State entity.
- Article 2
  - In the employment of laser systems, the High Contracting Parties shall take all feasible precautions to avoid the incidence of permanent blindness to unenhanced vision. Such precautions shall include training of their armed forces and other practical measures.

Articles of Protocol IV of the UNCCW

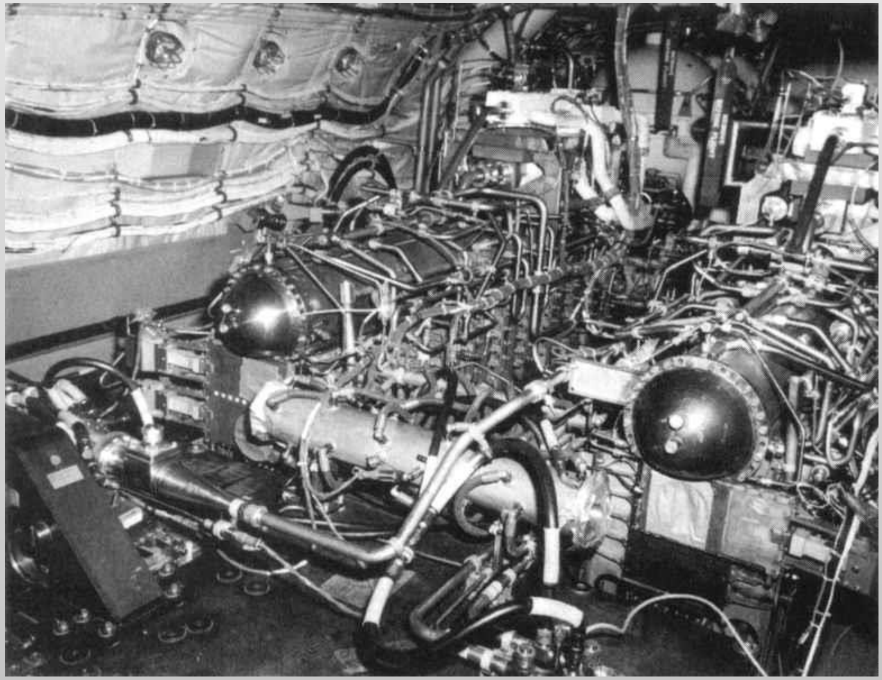
- Article 3
  - **Blinding as an incidental or collateral effect** of the legitimate military employment of laser systems, including laser systems used against optical equipment, **is not covered by the prohibition of this Protocol**
- Article 4
  - For the purpose of this protocol "permanent blindness" means irreversible and uncorrectable loss of vision which is seriously disabling with no prospect of recovery. Serious disability is equivalent to visual acuity of less than 20/200 Snellen measured using both eyes

Collateral damage scenarios

- Reflections from a target
  - Metal surfaces can be highly reflective
  - Specular reflections of laser light may cause eye damage
  - "Retinal damage induced by mirror-reflected light from a laser pointer", BMJ Case Rep. 2015 Oct 5; 2015.
- Exposure to the beam down-range of a target
  - Airliners and satellites
  - Less of a risk for tactical laser systems, but still possible damage to eyesight and sensors

Airborne Laser Laboratory (ALL) 1971-1983

- USAF research project aimed at providing missile defence for aircraft
- Gas Dynamic Laser mounted in a modified KC-135
  - Combustion of CO and N_2O
  - 10.6 micron wavelength
- 380 kW optical power at beam exit point [2]
- Intensity 100 W/cm^2 at 1 km range: enough to damage IR seeker optics [2]



Airborne Laser Laboratory – Outcomes

- In 1983 test disabled five Sidewinder AIM–9B missiles at 3 miles range [1, p3]
- Strong absorption due to water vapour and carbon dioxide @ 10.6 micron limits range
- Atmospheric turbulence causes the beam wavefront to distort
  - Results in spreading and loss of intensity on the target
  - Can be corrected using adaptive optics, but the technology did not become practical until the 1990s
- Project suspended 1984

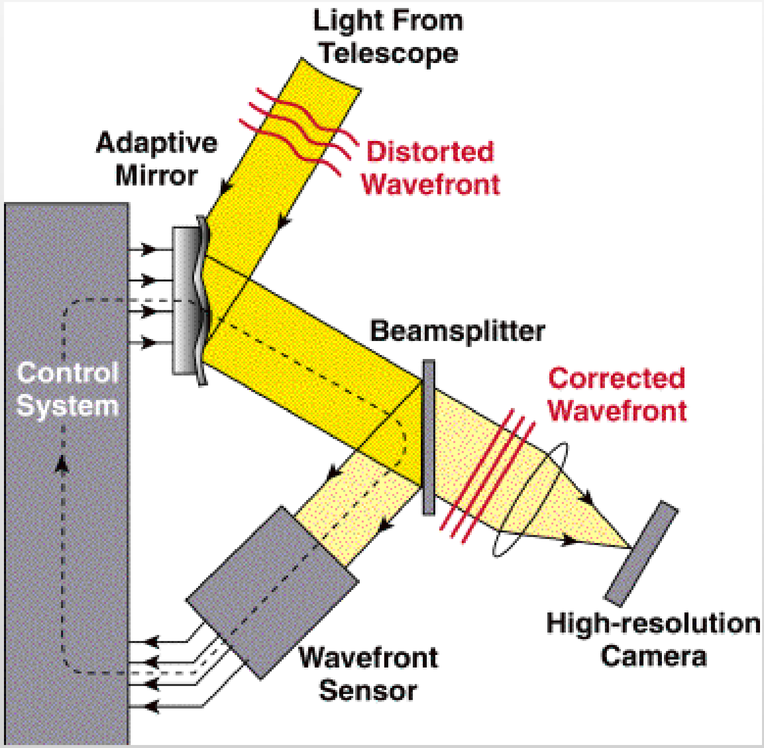
[1] "The Airborne Laser from Theory to Reality: An Insider's Account", Hans Mark, Defense Horizons, No. 12, April 2002.

[2] "Airborne Laser: Bullets of Light", R. Duffner, 1997.

[3] "Laser Weapons: The Dawn of a New Military Age", Bengt Anderberg, Myron L. Wolbarsht, 1992.

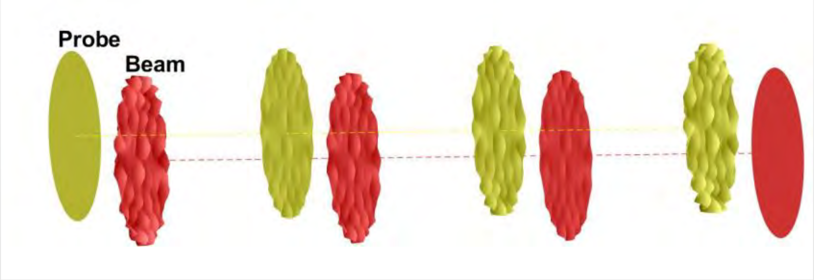
Scintillation

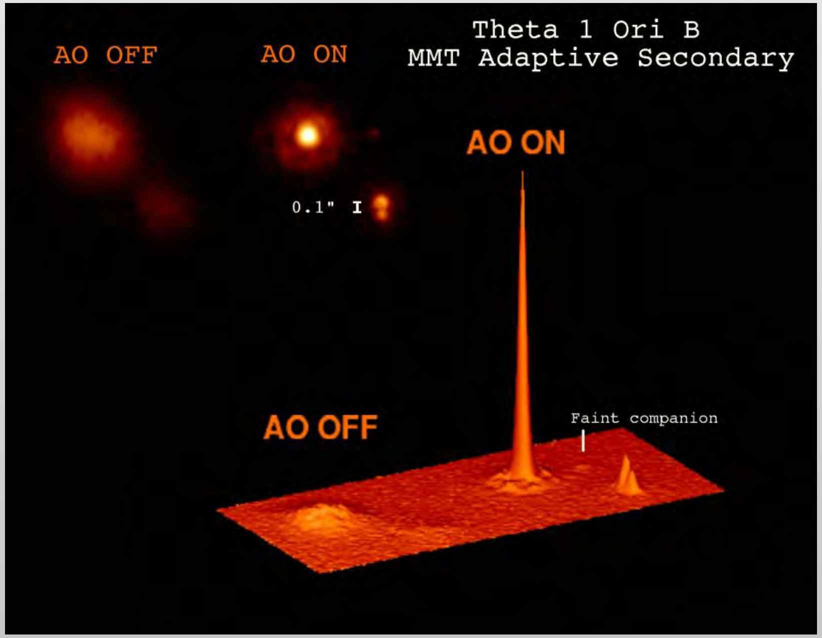
- Scintillation is collective term for beam spreading and beam wander due to turbulence in the atmosphere
  - ➢ Old problem in astronomy
- Adaptive Optics solution
  - ➢ Measure wavefront distortion
  - ➢ Invert and apply corrections using a segmented or deformable mirror
  - ➢ Wavefront initially distorted, straightens as it nears target area
- The idea is old, but did not become technically feasible until 1990s



Adaptive Optics for Beam Focusing

- Adaptive optics can be used for beam focusing in turbulence
- Measure wavefront distortion with a probe laser reflected from the target
- Apply inverse distortion to main beam using a deformable mirror
- Can restore sharp focus to an image or a beam that has spread due to scintillation





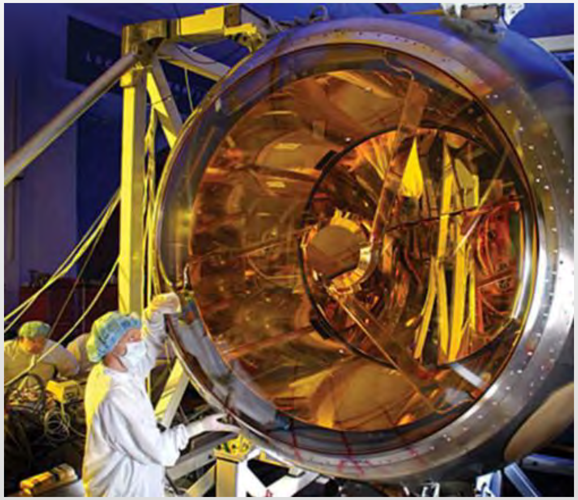
AO used to enhance images

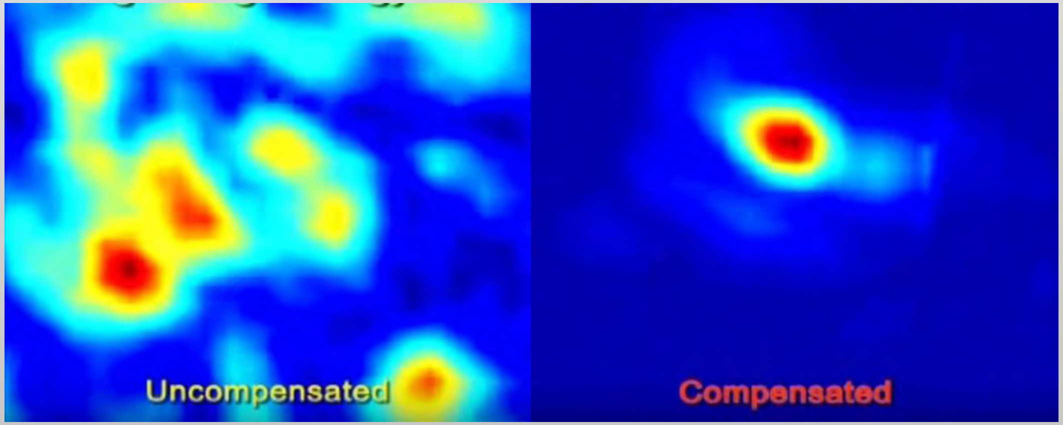
Airborne Laser Project 1996-2012

- US Missile Defence Agency project
  - To counter tactical ballistic missiles
  - COIL laser mounted in a 747
  - Megawatt optical power @ 1.3 microns, 3-5 second pulses
- 2007 Successful test of deformable mirror
- 2010 Successful engagement of a Scud-like ballistic missile (50-100 miles range?)
- 2012 project cancelled
  - Logistically unfeasible
  - Need 20-30 x power for theatre use

Airborne Laser – Atmospheric Compensation

- The Airborne Laser used a deformable mirror to compensate for turbulent wavefront distortion and focus the beam on target
- Screen snapshots showing effect of Atmospheric Compensation on beam profile at the target [1]

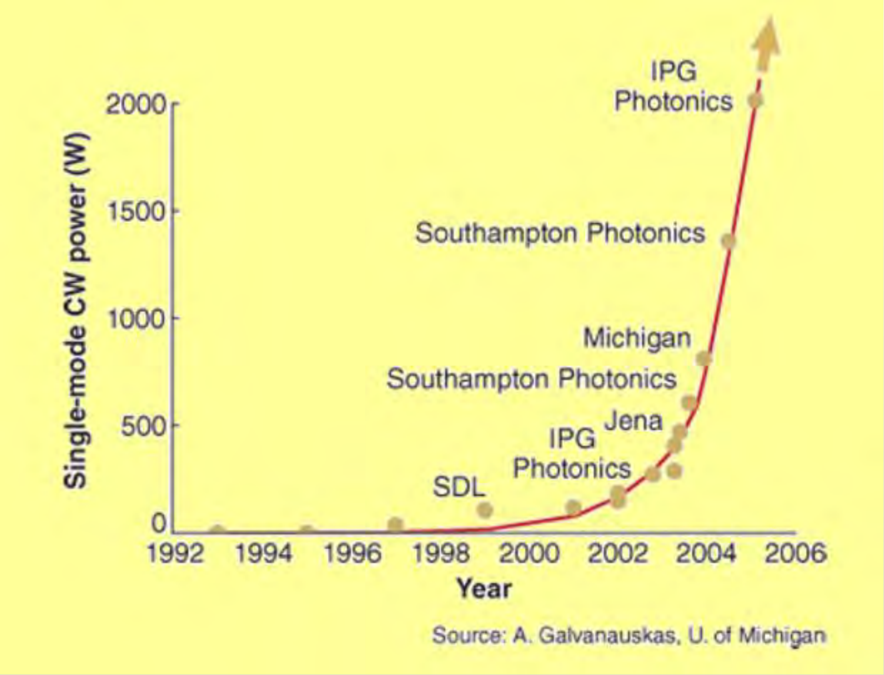




[1] "Airborne Laser ABL Executive Update 2008", https://www.youtube.com/watch?v=r-dEXaSJWME

High Power Fibre Lasers

- Fibre lasers have increased significantly in power since 1990
- Optical fibres doped with a heavy metal, e.g.
  - Ytterbium 1030-1080 nm
  - Erbium 1400-1600 nm
  - Overlap with atmospheric absorption windows
- 10 kW single-mode fibre lasers available since 2009
- Efficiency > 25%

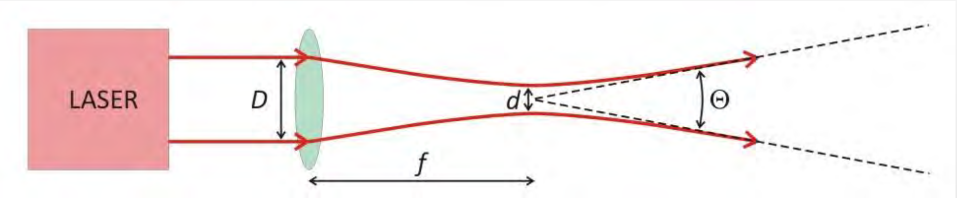


High Power Fibre Lasers

- Industry leader IPG Photonics (USA) makes lasers for welding, cutting, micro-machining
- Advantages of fibre lasers
  - Robust: do not contain sensitive optical components
  - High surface area to volume ratio: easy to cool
- Indicative cost $200k to $400k USD
  - Export controlled
  - Second-hand market

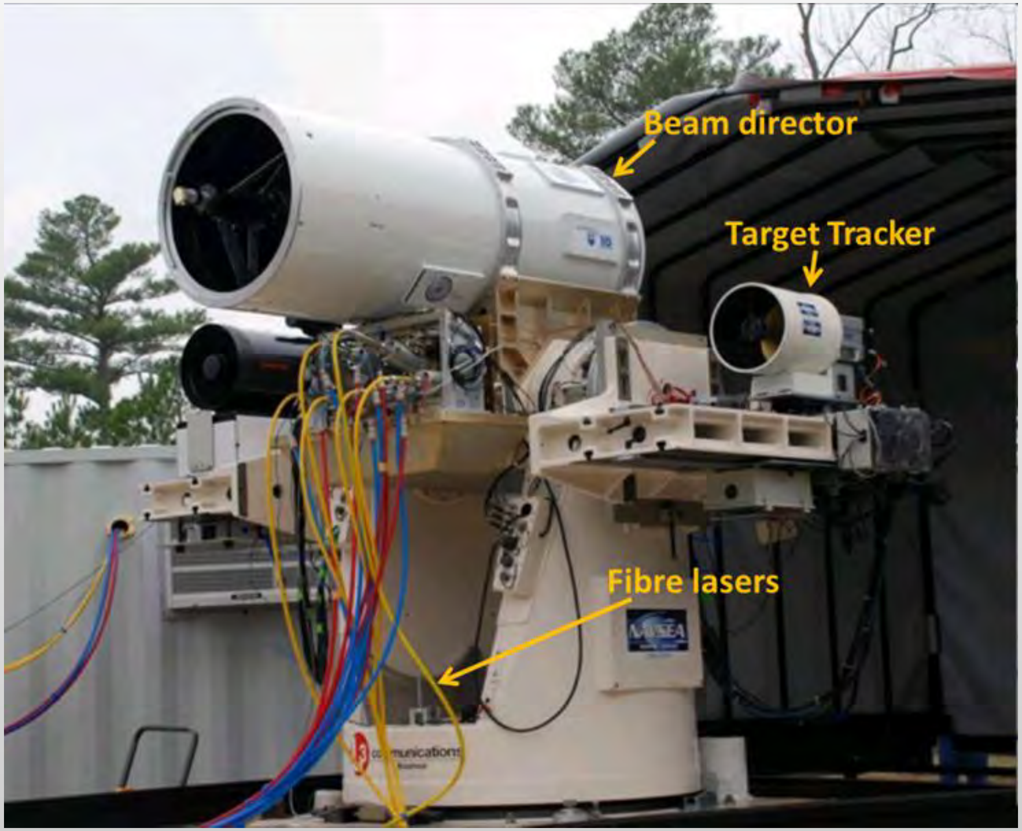
Single mode fibre lasers

- For directed energy applications single mode fibre lasers are vital
  - Minimal spot size and beam divergence
- Highest single-mode power available from a fiber laser is 10 kW
  - IPG Photonics, single mode, $M^2 \sim 1$
  - Entire system (including cooling) is about the size of two refrigerators
- Water cooling: 8 litres per minute per kilowatt
  - Sprangle, 2008



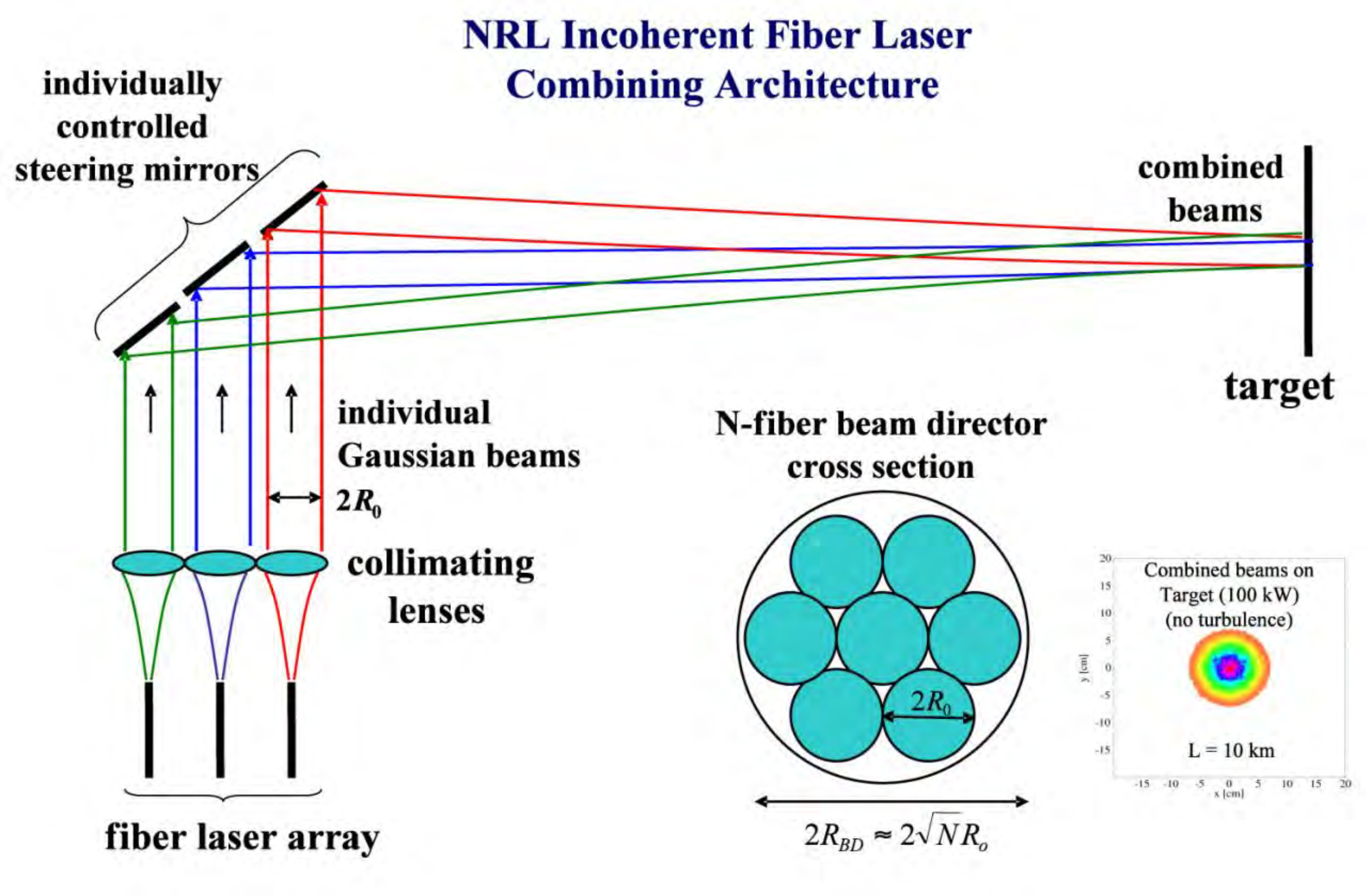
US Navy Laser Weapon System (LaWS)

- 6 x 5.5 kW welding lasers
  - 1.064 micron wavelength
  - Water vapour transmission window near 1.045 micron
- Beams overlap at target
- 33 kW output beam
  - 25% efficiency
  - 130 kW required for lasers and cooling system
  - Assuming 150 kW total power required, cost of fuel is 1.5 cents/second of operation
- Weight
  - Lasers + coolers ~ 6 tons
  - Mount + optics ~ 4 tons (?)



LaWS Beam Control System

- Combine beams from multiple lasers and overlap on the target
- LaWS based on US Naval Research Lab experiments

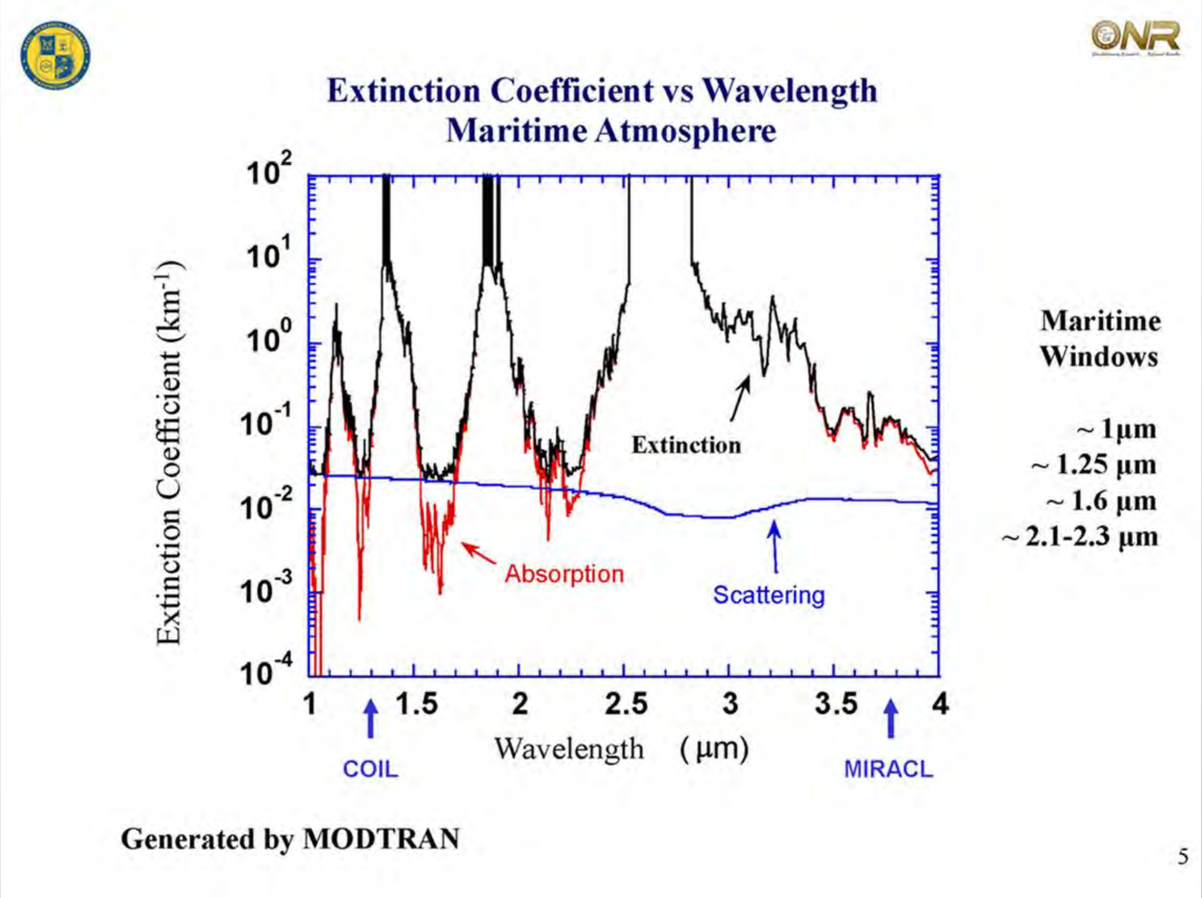


USN Laser Weapon System (LaWS)

- LaWS trials against UAVs, small boats, and an RPG warhead
- Engagement range approximately 1.5 km

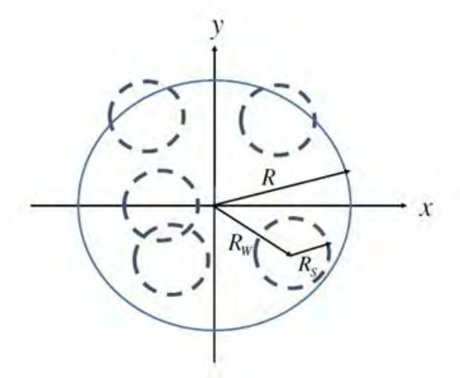
Atmospheric absorption/scattering

- Absorption and scattering
  - Water vapour and carbon dioxide, other aerosols
  - Minimize by operating in “transmission windows”
- Thermal blooming
  - Heating of the air changes refractive index
  - Problem for > 100 kW beams

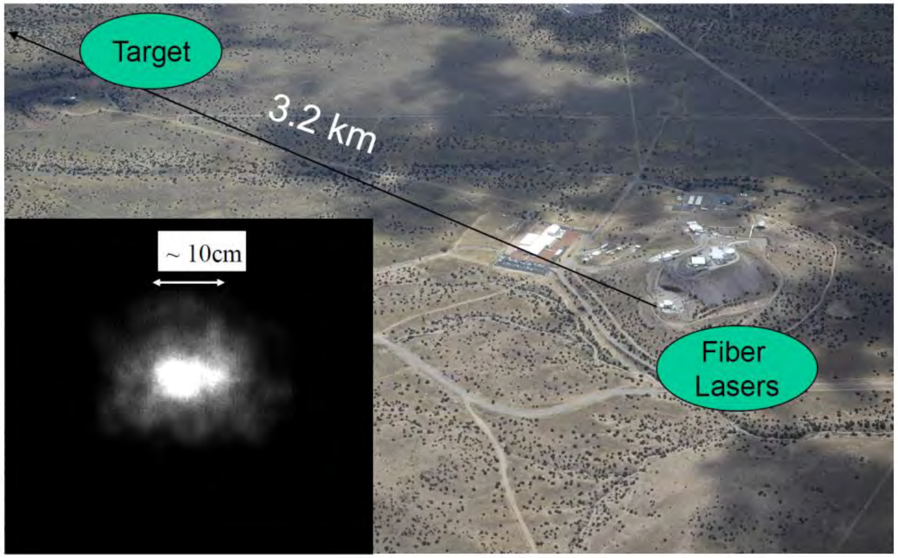


Turbulence compensation

- Weak turbulence induces beam wander or jitter
- Time-scale 20 milliseconds
  - [Sprangle, 2008]
- LaWS uses steering mirrors to direct the individual beams
- Can compensate for beam wander, but not beam spreading
- US Naval Research Laboratory tests
  - Focused four beams at 3.2 km on test range
  - 10 cm spot size

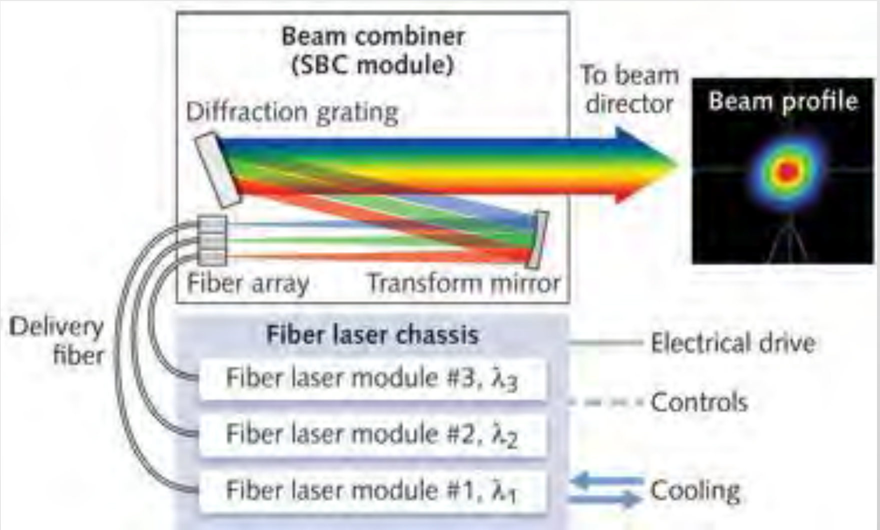


Incoherently combined fiber lasers, ~ 5 kW, cw, M^2 ~1



Lockheed-Martin ATHENA

- ATHENA
  - Advanced Test High Energy Asset
  - 30 kW combined fibre laser
  - Intend to increase power to 60 kW and mount in truck for US Army (HELMTT)
- Spectral beam combiner
  - Combines outputs of many lasers at slightly different wavelengths into a single beam using a Prism
  - Simplifies beam control problem
- 2017 – power increased to 58 kW
  - 43% efficiency



Lockheed-Martin ATHENA

- 2015 trial against truck on platform with running engine
  - Truck disabled at ~ 1.5 km
  - Burn time unknown
- 2017 counter-UAV trials
  - 30 kW version
  - 5/5 shoot downs of Outlaw UAV (length 2.7m, wing span 5m)
  - Beam targets the tail assembly
  - UAVs crash after structural failure of horizontal stabilizer
  - Burn time > 5 seconds
  - 150 kJ optical energy ~ 10 x 0.50 cal

MBDA Laser Directed Energy Weapon

- 2017 UK MOD awards £30 million contract to MBDA for LDEW Capability Demonstrator Program
- MBDA leads the Dragonfire consortium (MBDA, Dstl, Leonardo, QinetiQ)
- Continues development of MBDA's 40 kW experimental laser weapon
  - 4 x 10 kW IPG Photonics fibre lasers
- Prototype to be delivered in 2019
  - Will be 50 kW class
  - Coherent beam combiner
  - For use against mortars, missiles, counter-UAV, dazzling

Possible Countermeasures?

- Critics of laser weapons say they could be countered by white paint or a highly reflective coating
  - "…White paint can reflect 90 percent of laser energy. Now you need a laser that's ten times bigger" [Philip Coyle, Asst. Sec. Def. 1994-2001]
- Little discussion in the open source literature regarding this issue…
- Boeing Airborne Laser ground test with a missile body painted white
  - "…white paint had no effect on the lethality of the directed energy beam and did not require a longer duration lase, nor did it result in a reduction of energy required to burn through the booster case." – Missile Defence Agency [1]
- MBDA tests with 40 kW combined fibre laser
  - Tested effectiveness of reflective armour
  - Claim that dust on mirror surface leads to even faster destruction of the target

Conclusions

- Laser weapons are better suited for short range defence applications
- Key technology developments for tactical weapons:
  - High Power Fibre Lasers
  - Adaptive optics
  - Spectral beam combining
- Absorption/Scattering losses are more difficult to counter
- What are expected losses due to water vapour, dust and smog in the areas in which we operate?
- Have laser weapons been tested under a realistic range of environmental conditions?

Defence Technology Agency

Is the Environment the Ultimate Jammer?

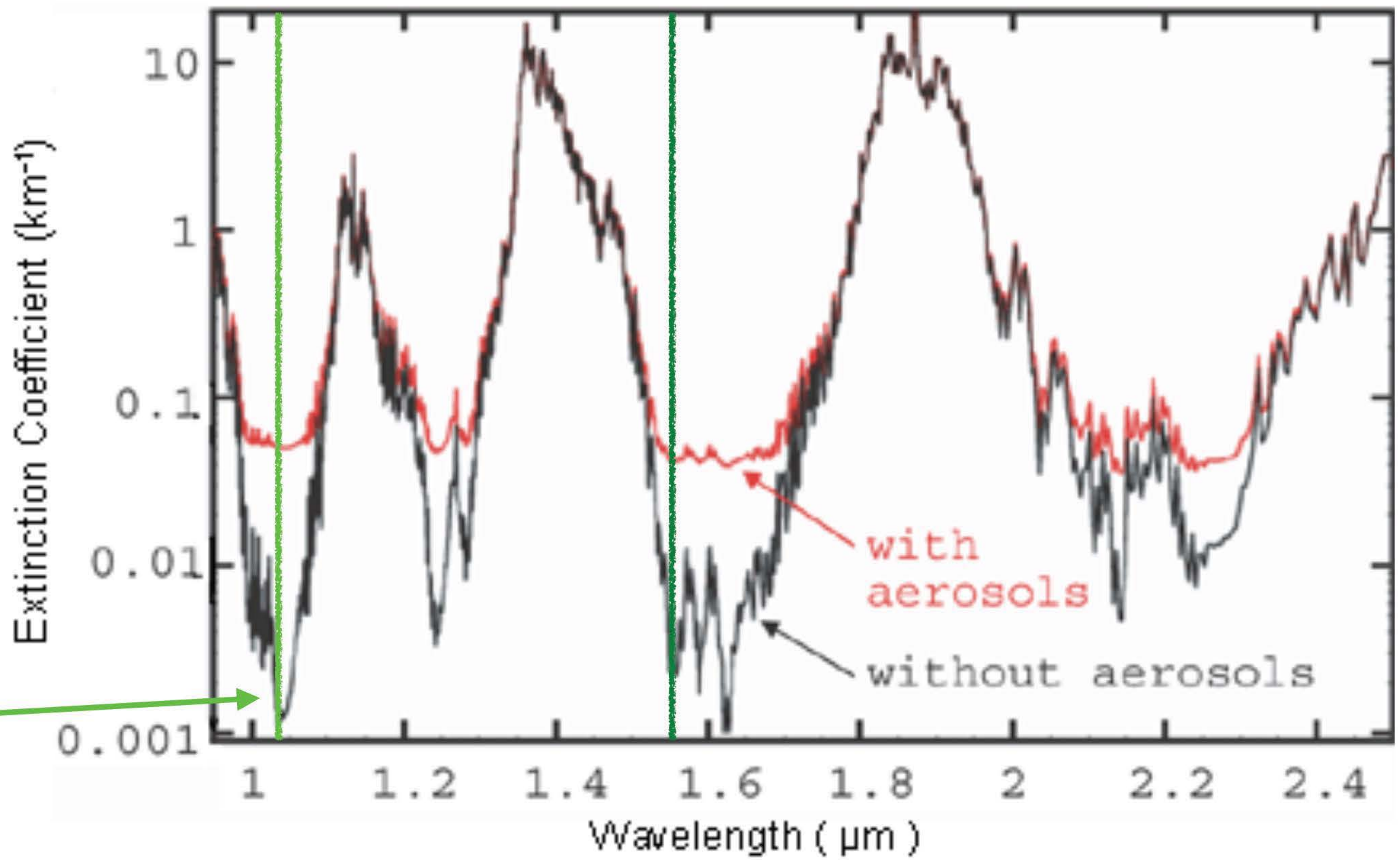
Defence Technology Agency

Understanding Sensor & Weapon Design

Sensors designed for *Theoretical*

Operational case contains "aerosols"

LaWs



Example laser range finder at 1.54 μm shows high variability in *E*

Modelled using MODTRAN for a midlatitude summer, maritime, v=50km

P. Sprangle et al., NRL

What are Aerosols?

- "Formally" it is a *colloid* of fine solid particles or liquid droplets, in air or other gas.
- A suspension of particles in the atmosphere, *but often only think of the particles themselves*.
- Aerosol Distributions studied include different *modes*:
  - Coarse particles (sea salt, dust, sand, volcanic ash, PM_{10})
  - Fine particles (often anthropogenic, nitrate, sulfate, $PM_{2.5}$)
  - Ultra fine particles (UFPs, D<100nm)
- Most research "in aerosols" relates to health effects and/or climate effects but there are other operational reasons to study aerosols, applicable to the NZDF.
- In NZ, PM_{10} is most often measured, why? Why not $PM_{2.5}$? Like most of the world!

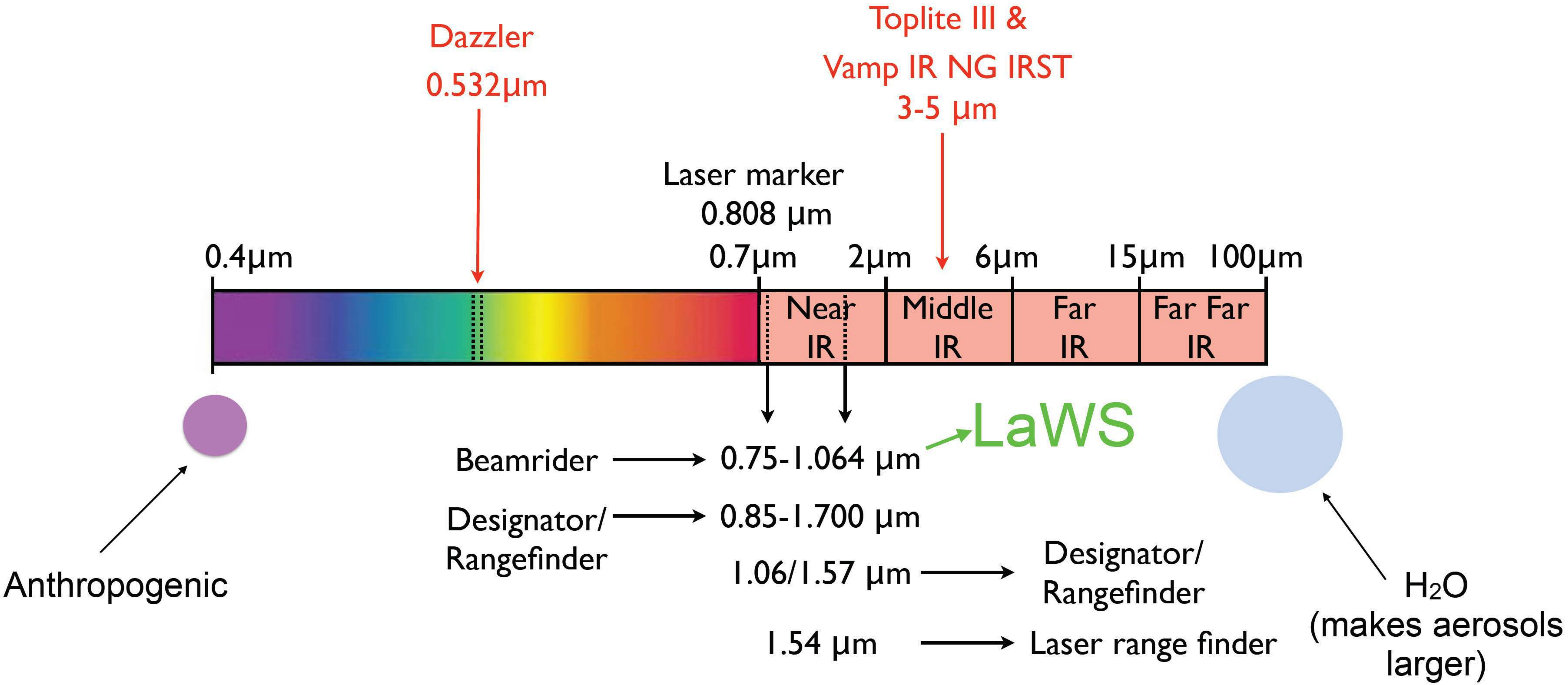
dta Defence Technology Agency

Measurement Techniques

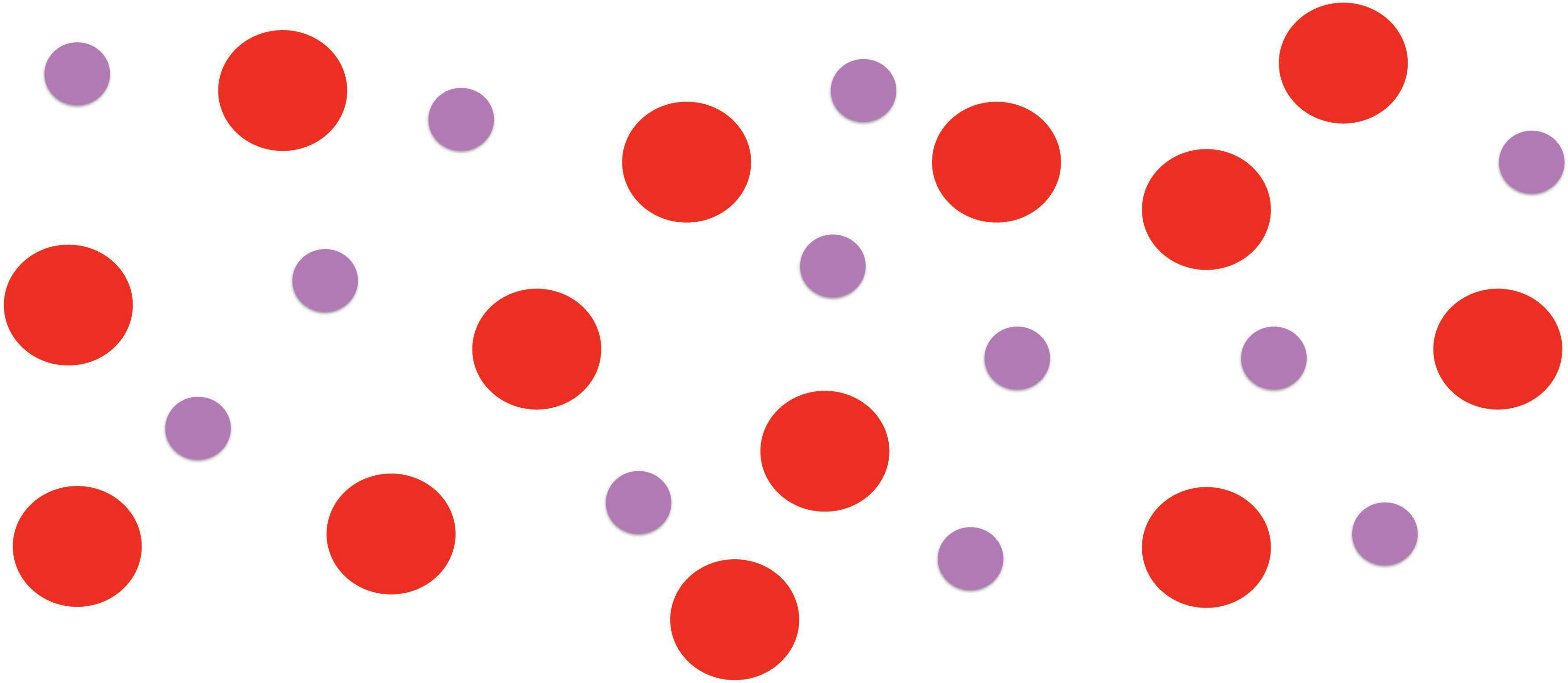
- Aerosols may be measured (directly or remotely) or modelled.
  - Satellites (MODIS, GOES-E, GOES-W, ATSR, MISR, AVHRR etc.) offer good spatial coverage, but limited temporally, vertically,
  - Models offer similar advantages but make standard assumptions of conditions across large domains (MODTRAN*, LOWTRAN),
  - Direct measurements represent the best resolution and temporal sampling, but sampling locations are generally sparse.
- Aerosol amounts may be expressed as a direct concentration (μg/m^3) or aerosol extinction (*E*), which represent point measurements or as integrated quantities (aerosol optical depth - AOD).

Defence Technology Agency

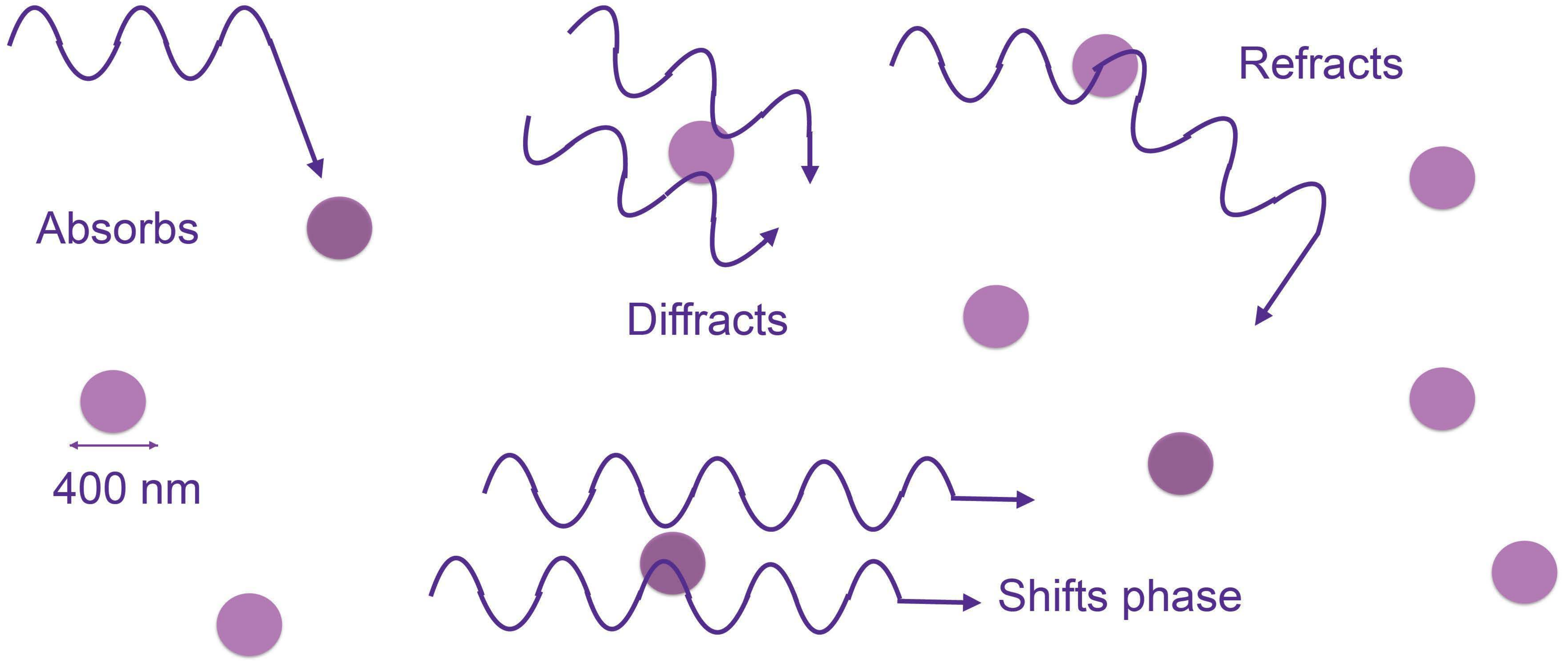
The “Electro-optical Spectrum”



Electro-optics 101



EMR interacts with Aerosols

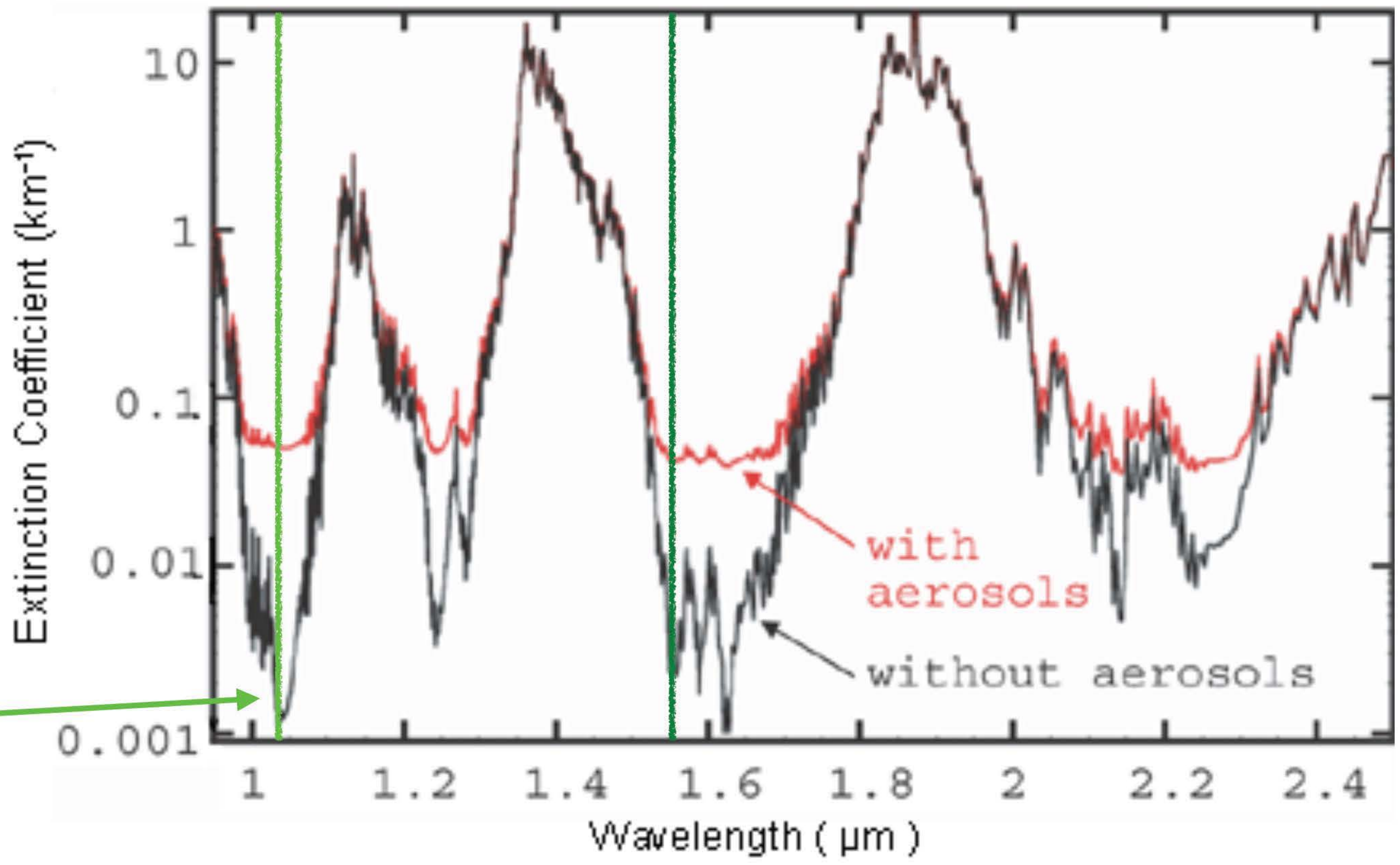


The Environment is variable

Sensors designed for

Theoretical vs. Operational Case

LaWs



Example laser range finder at 1.54 μm

Modelled using MODTRAN for a midlatitude summer, maritime, v=50km

P. Sprangle et al., NRL

Aerosol Terminology

- Aerosol Optical Depth (AOD) is a measure of the extinction of the sun by aerosols. It is *dimensionless*.
- AOD = 0.05-0.1 for clean maritime conditions
- AOD > 0.4 hazy conditions (Los Angeles)
- AOD has been over 3 in China!
- Extinction is defined as : E=AOD/h
- While Visibility (km) is basically the Extinction's inverse:
  - v = 3.912 / E
  - China ~ 1.3 km, clean maximum 296 km due to Rayleigh limit, "theoretically"

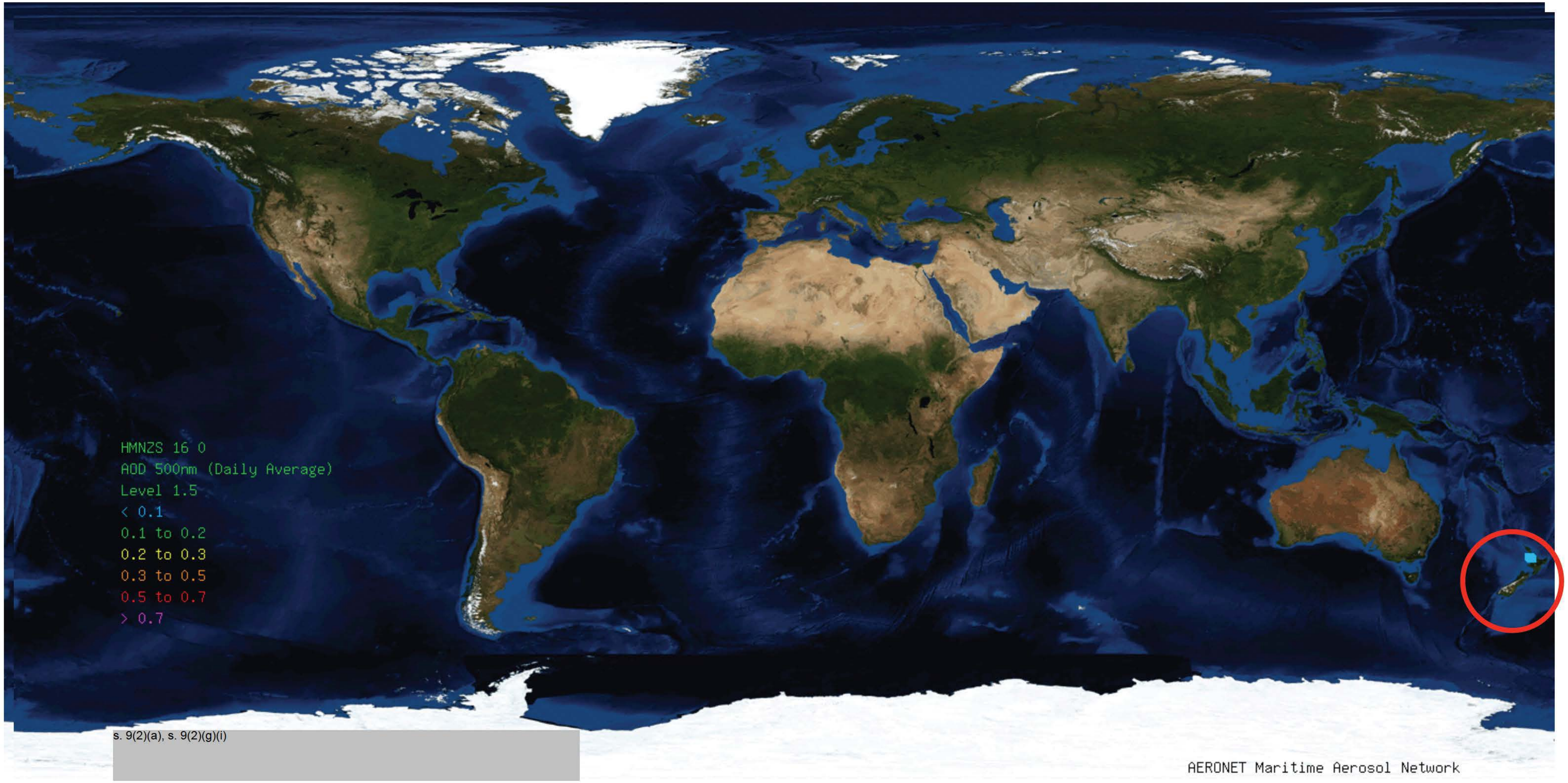
NASA Microtops II Sunphotometer

GPS

line up the spot in the middle for 5-10s

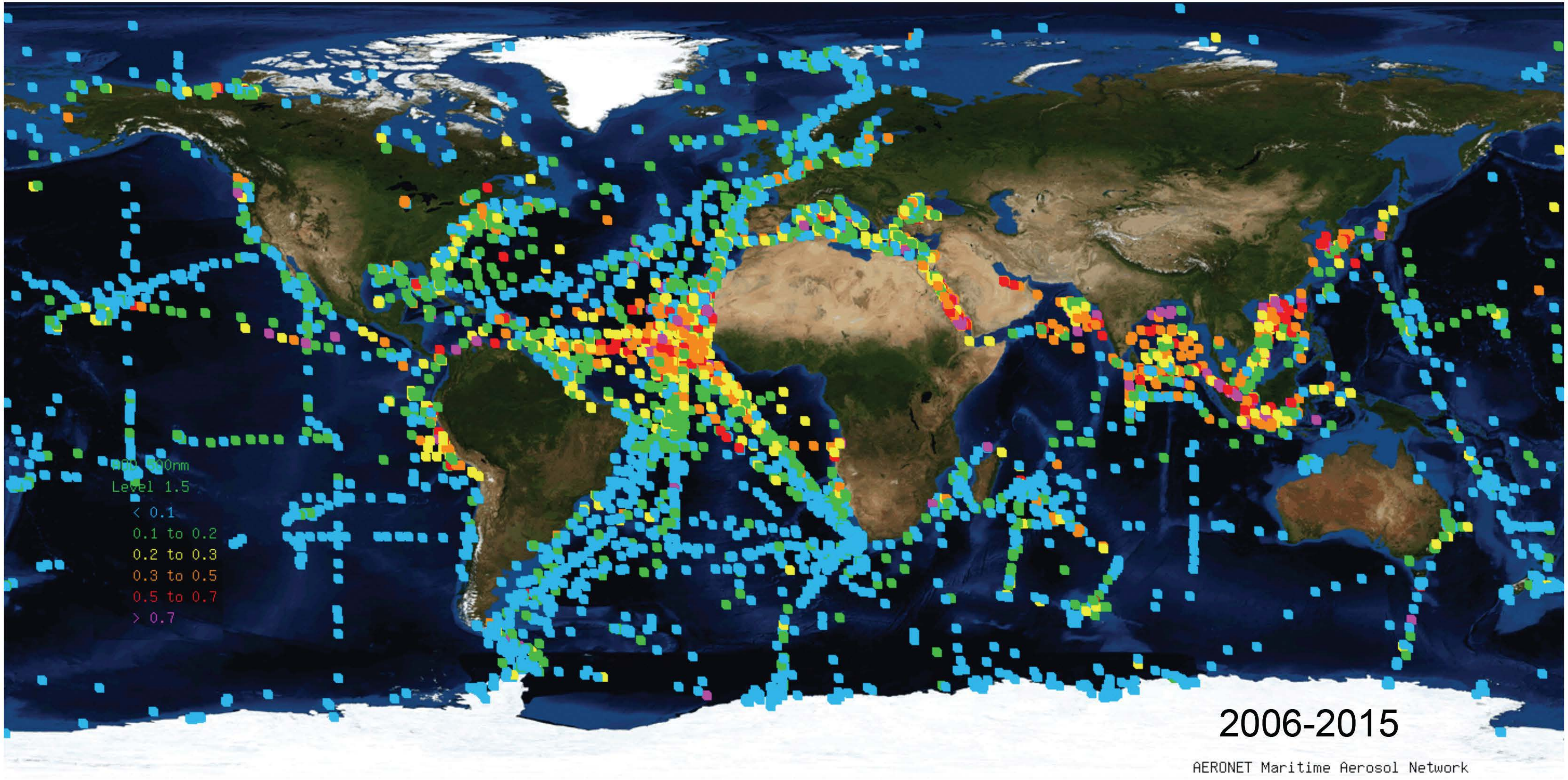
dta
Defence Technology Agency

NZ coast - Low AOD ~0.07



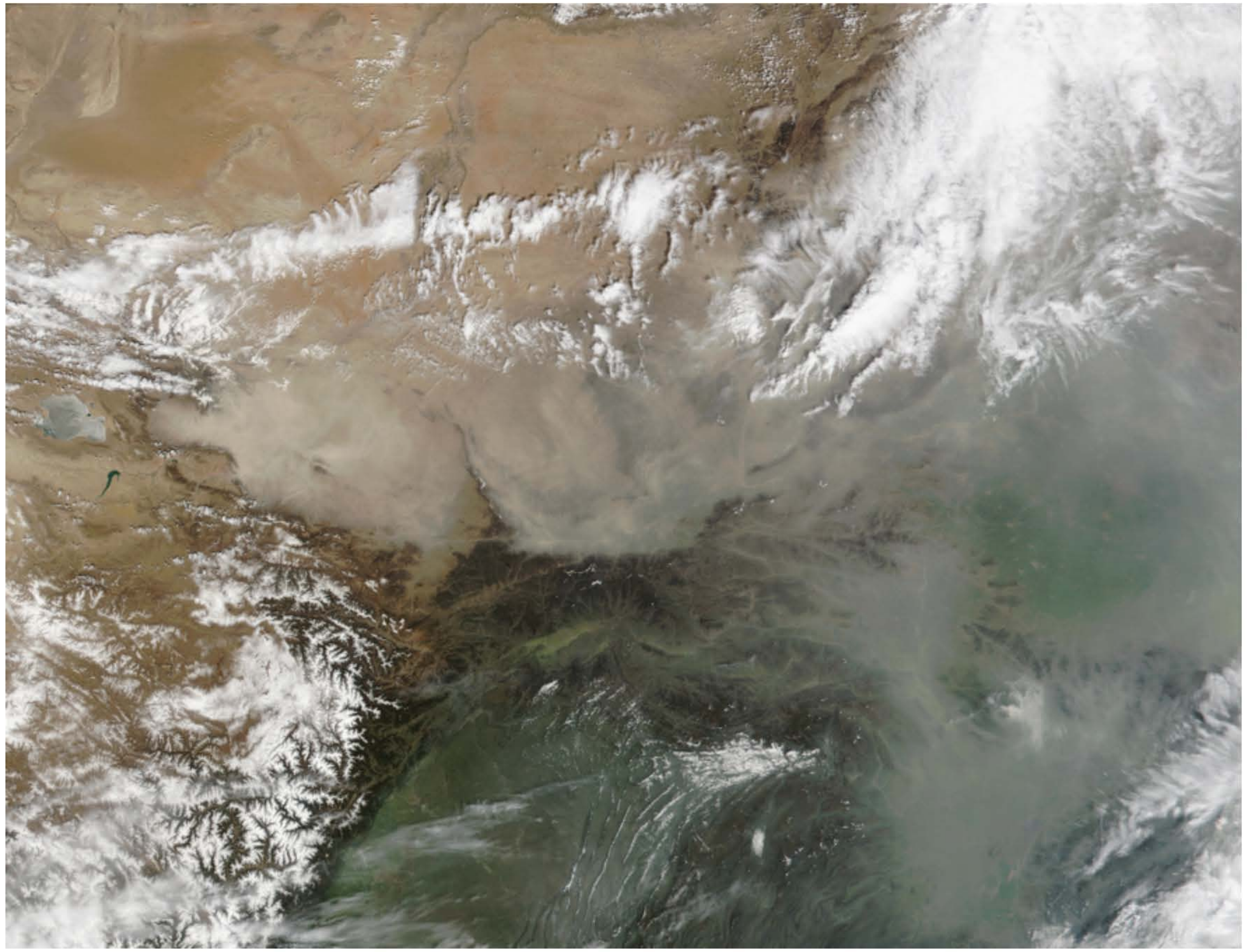
Defence Technology Agency

Maritime Aerosol Network
$AOD_{0.5\mu m}$

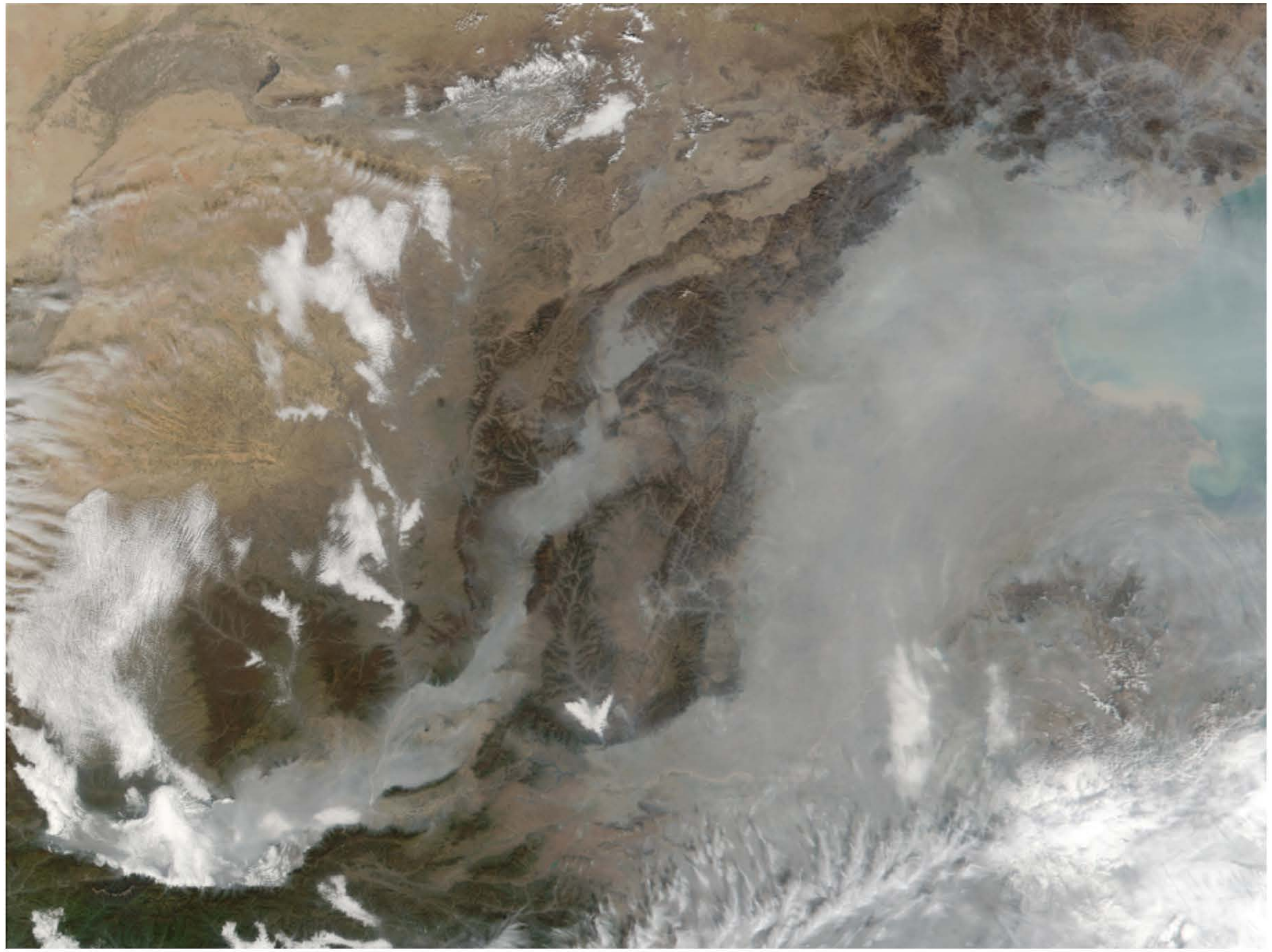


NASA MODIS satellite

visibleearth.nasa.gov



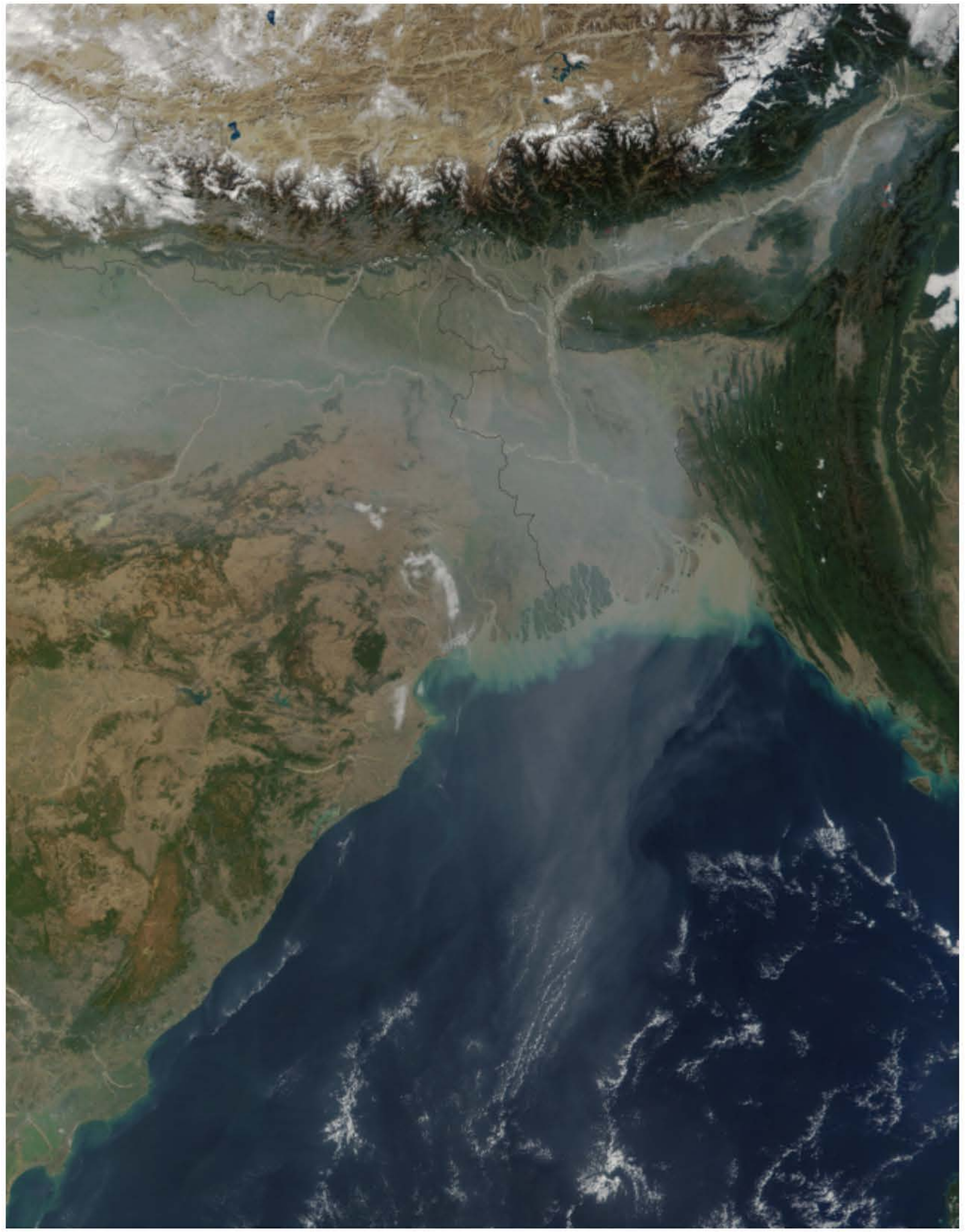
Dust storm, Eastern China, 2002

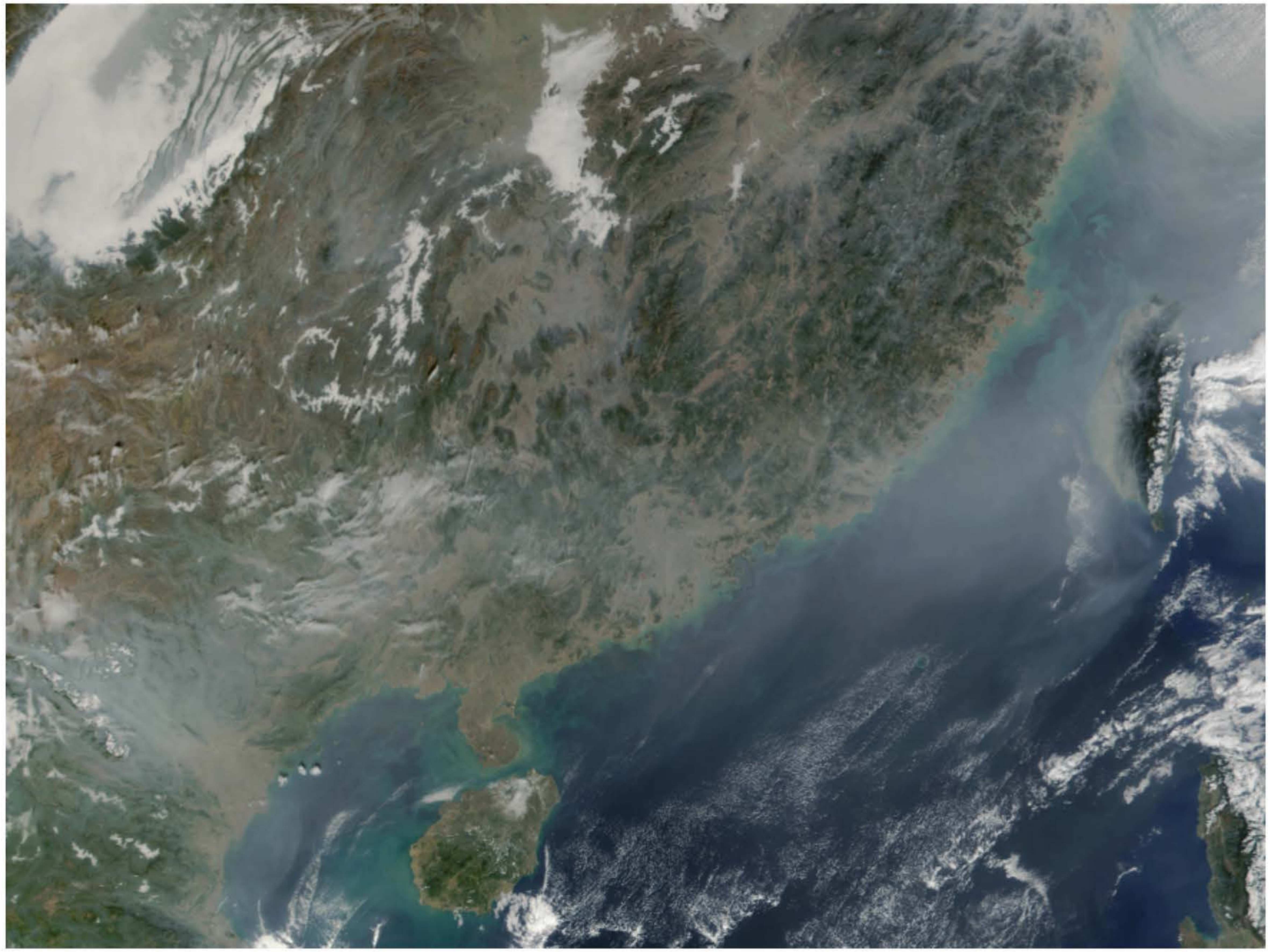


Anthropogenic,Yellow River, 2001

NASA MODIS satellite

visibleearth.nasa.gov



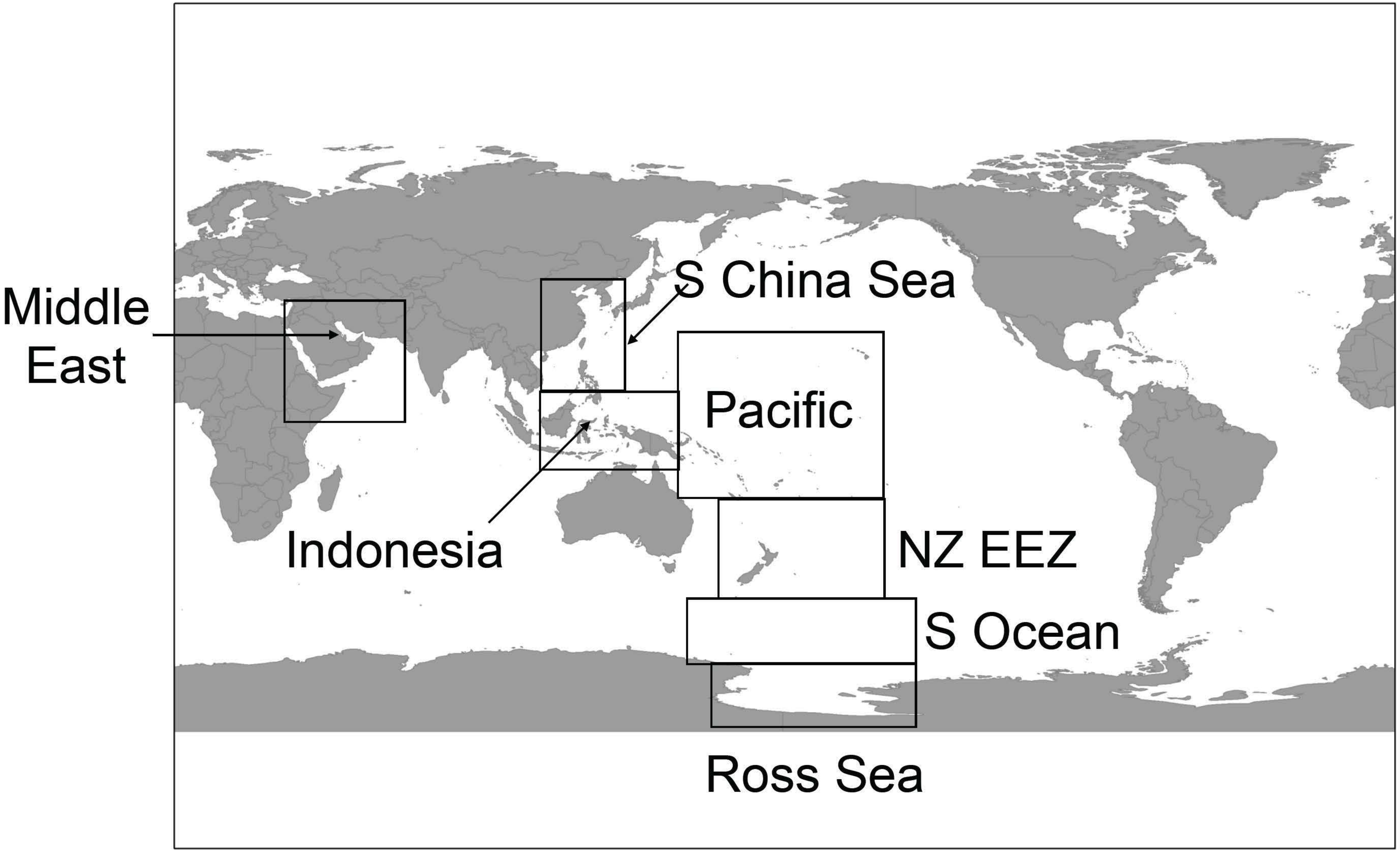


Anthropogenic + Fires, S China, 2002

Anthropogenic, Bay of Bengal, 2002

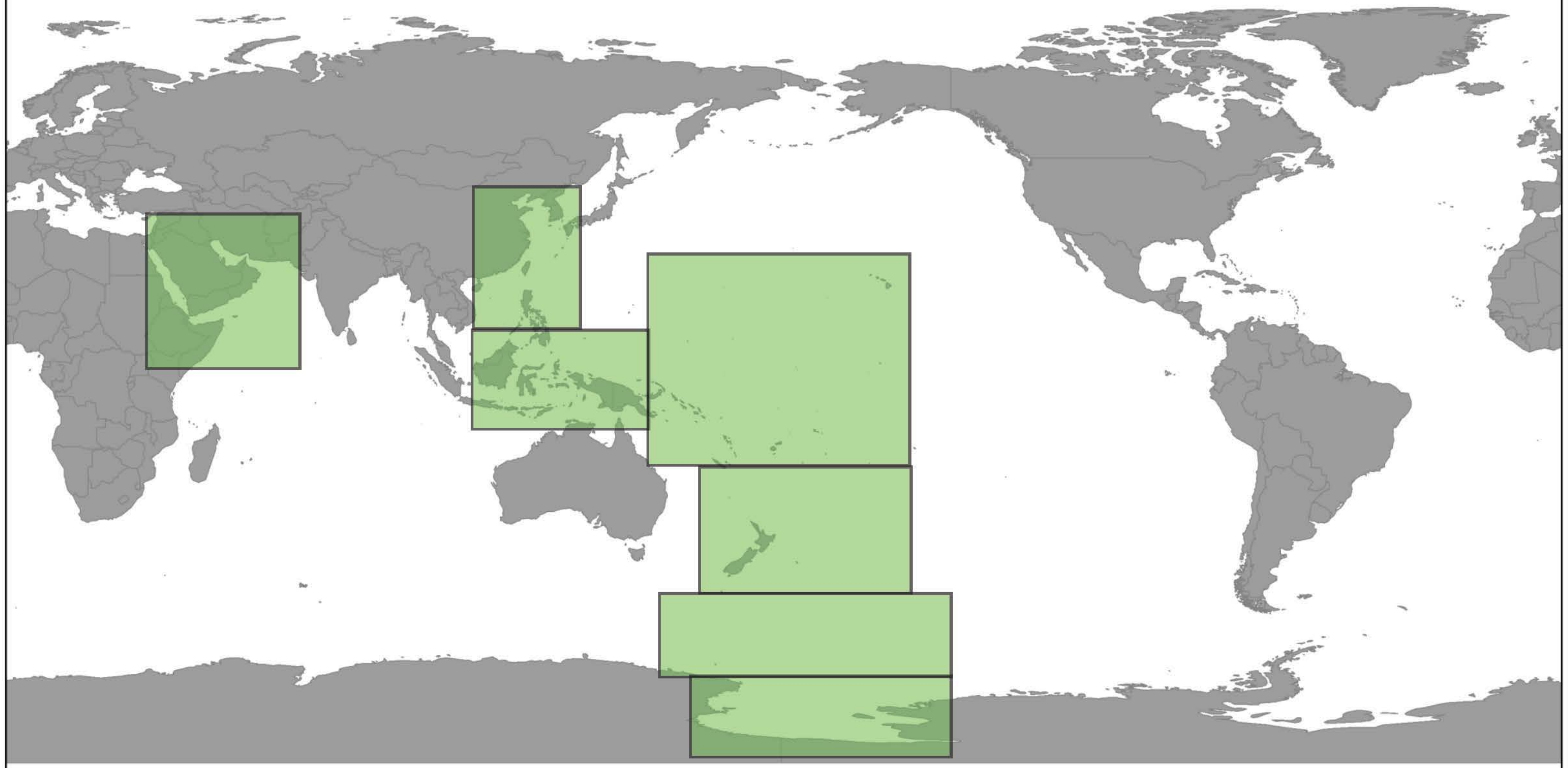
dta Defence Technology Agency

Oceanic Zones of Interest to the NZDF



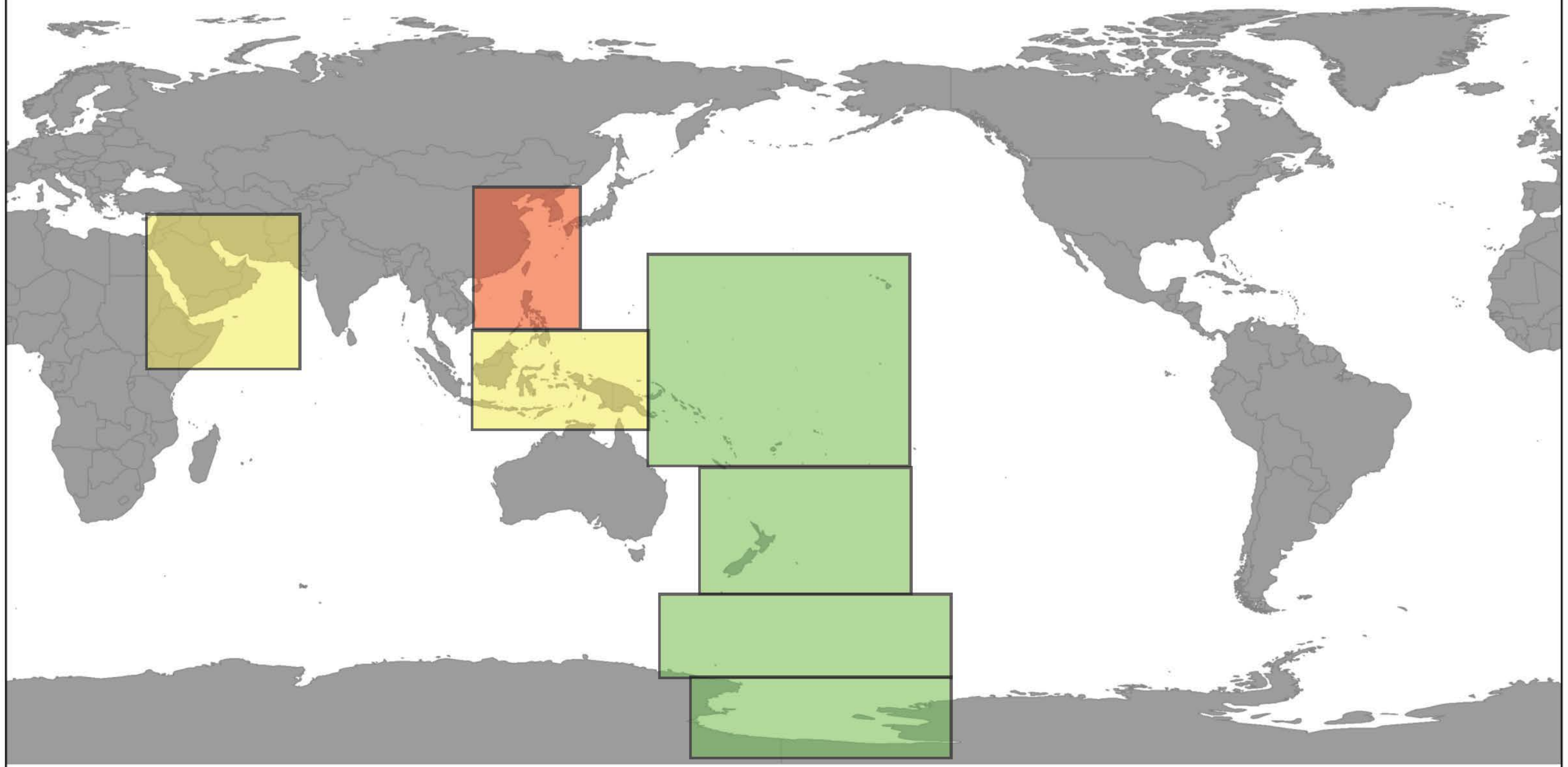
What is the NZDF's presumed capability?

"Presumed"



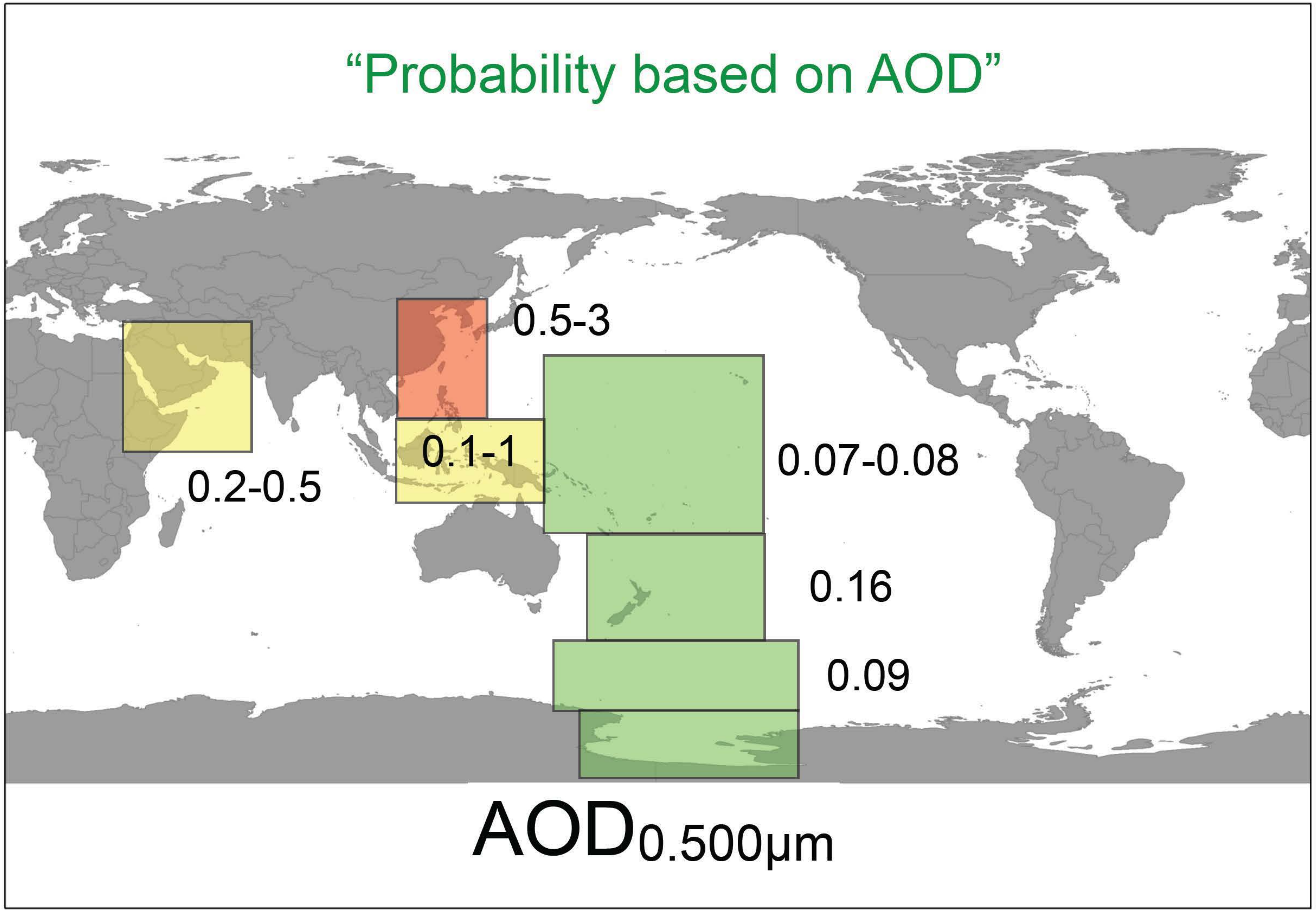
Laser @0.523 μm

"Likely conditions"



dta
Defence Technology Agency

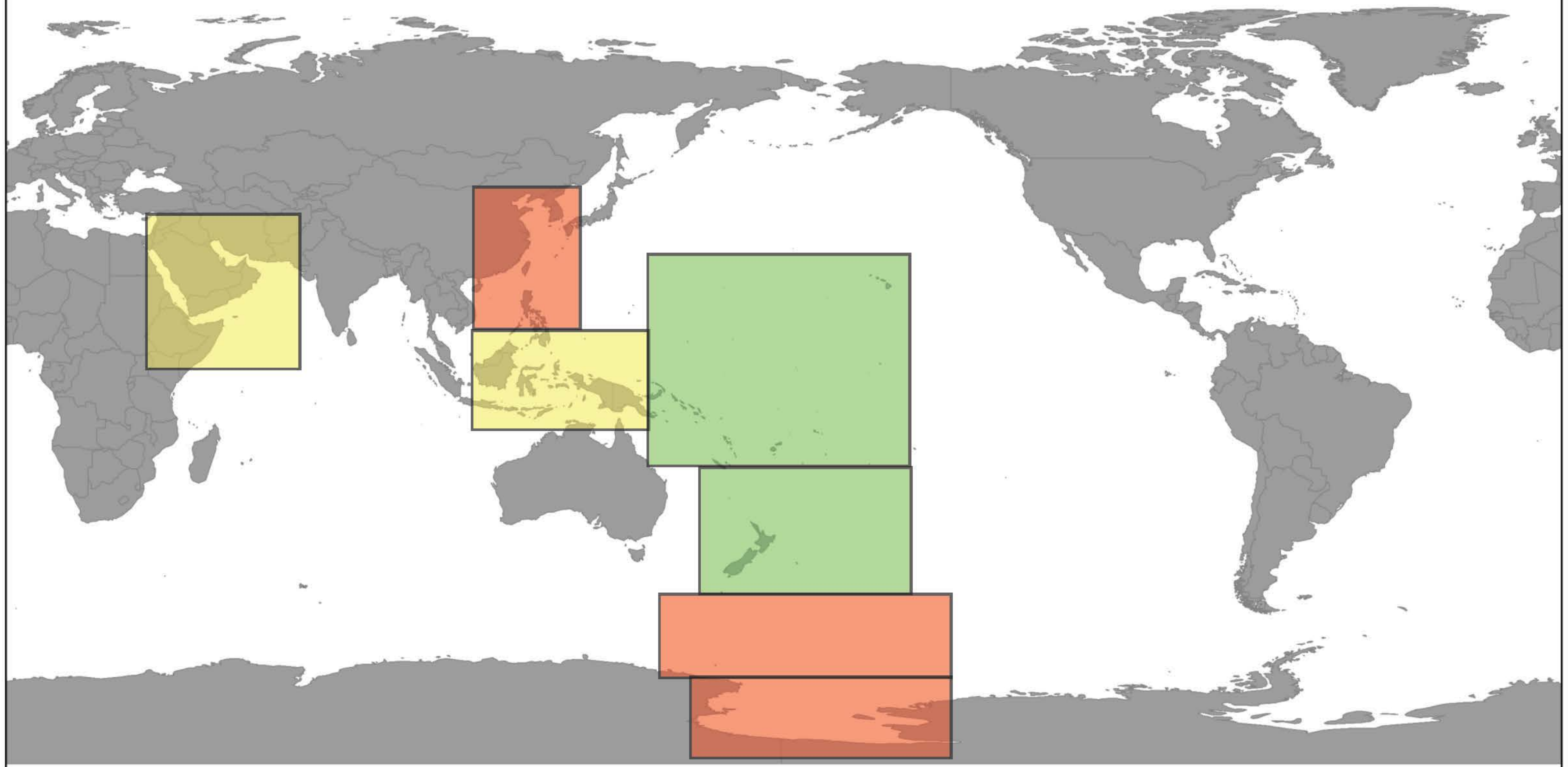
Laser @0.523 μm



Defence Technology Agency

LaWS ~1 µm

“Probability based on AOD and Humidity”



Defence Technology Agency

Rapid Environment Assessment

- Cannot assume that weapons/sensors will work under all operating conditions.
- *Rapid Environmental Assessment* (REA) should be used to understand how the environment will influence a particular sensor.
- Key tools to: sun photometer, humidity, other met parameters, forecasting, ceilometer, satellites, LIDAR, DOAS, UAVs.
- Future work to look at specific threats for different weapons/sensors and make recommendations for REA.