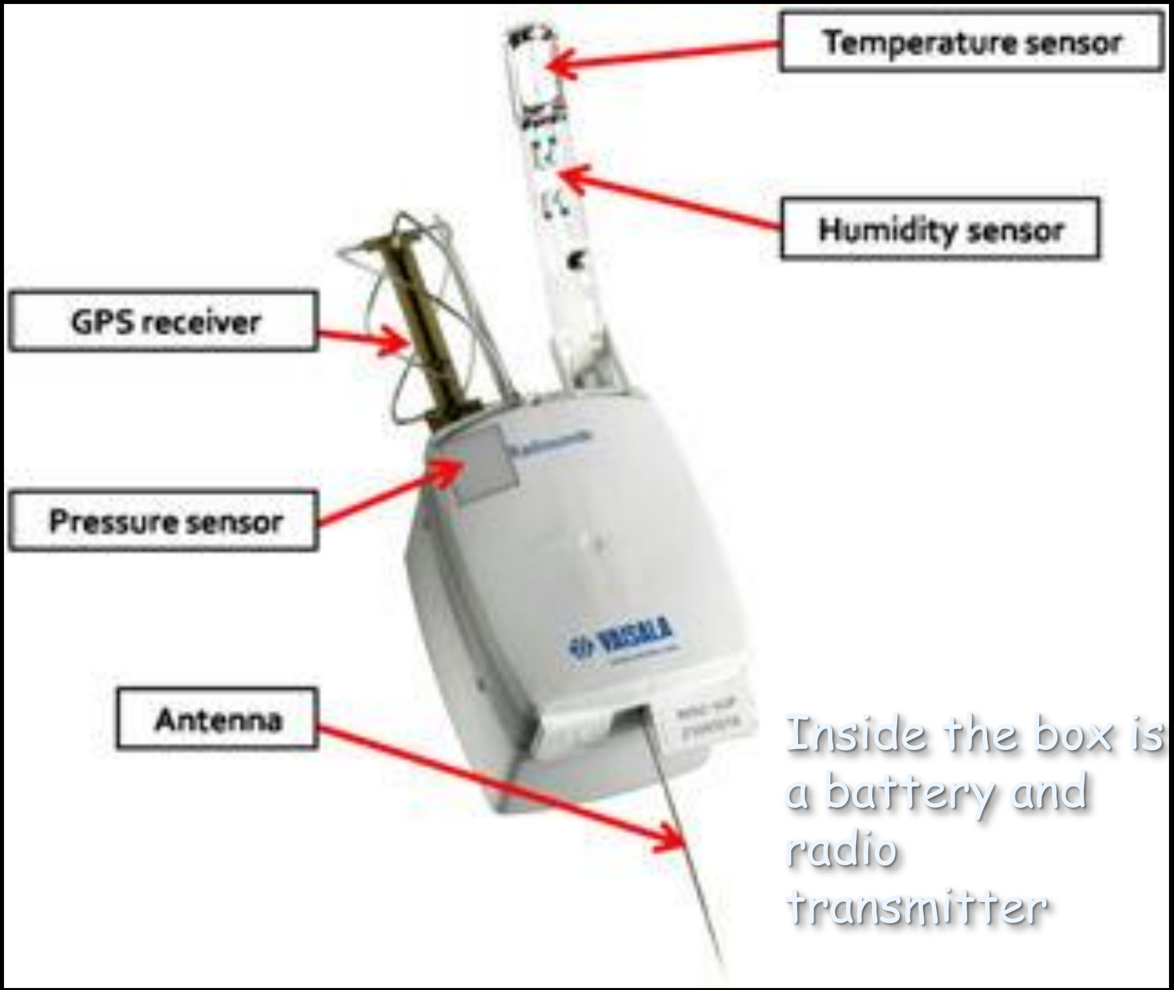
Understanding weather and the weather forecast

Week 14 The Global Weather Observing System – Aircraft and Satellite

Terry Hart

Radiosonde

Balloon with parachute and radiosonde



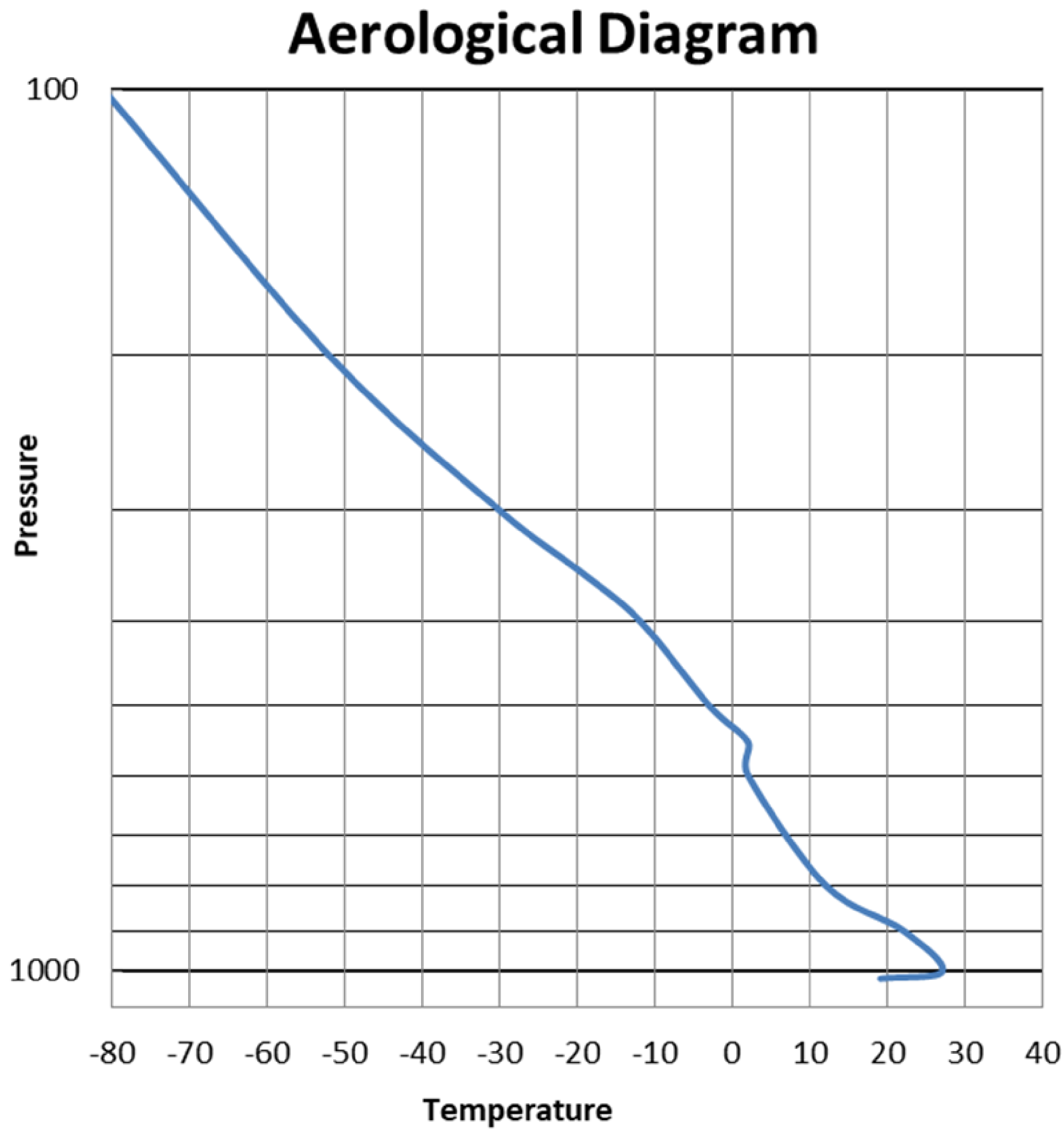
The altitude and the wind and direction are now mostly derived from GPS tracking

Video: US National Weather Service – launching a radiosonde

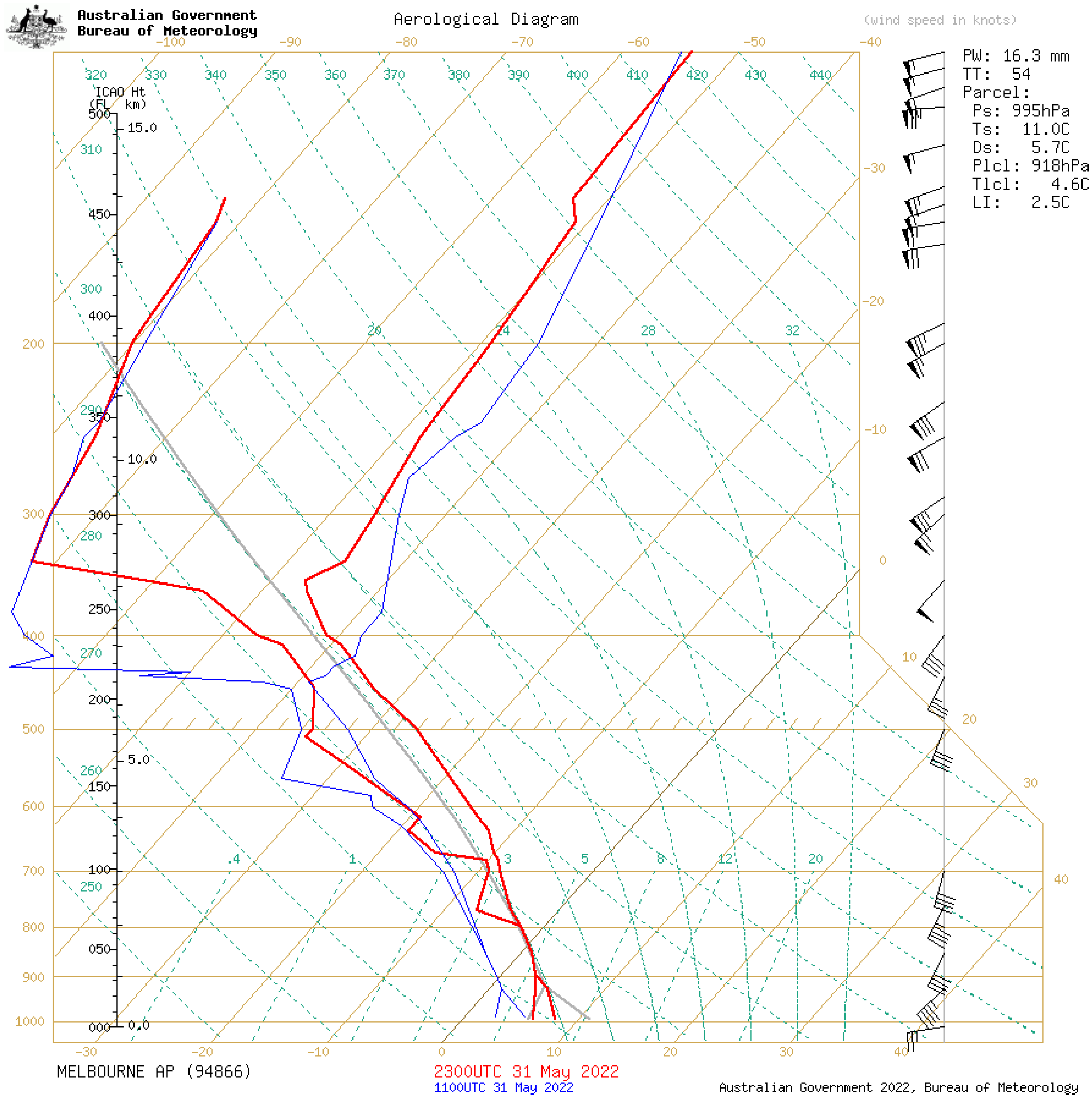
Aerological diagrams

- Plots of data obtained from radiosonde flights
- They show air temperature and dew point in the upper atmosphere
- Upper winds are also plotted on the diagram
- Used in general forecasting but are also vital in aviation forecasting
- Data plotted on to a Skew T – log P diagram

Video: Weather Balloons and Radiosondes
(apologies for the cartoon approach!)



Aerological Diagram
100
1000
Pressure
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40
Temperature



Melbourne

Red
9 am 1 June

Blue
9 pm 31 May

In the late 1930s, Bureau observers took upper air temperature readings from thermometers on the struts of aircraft like this Bristol Bulldog pictured at RAAF Laverton in Victoria. Photographed on 9 October 1937 were (from left) Bureau officers Joe Walpole, Alan Martin, Errol Mizon and Keith Hannay (later Regional Director, Victoria). At rear, Fred Rose and the pilot, F/O Richard Cohen.


Introduction to Aircraft Meteorological Data Relay (AMDAR)
Creative Commons Pieter van Marion


Creative Commons D'Arcy Norman

AMDAR can measure or derive the following meteorological parameters with very accurate time, pressure altitude, and latitude and longitude coordinates:

- Air temperature
- Wind speed and direction
- Pressure altitude (barometric pressure)
- Turbulence
- Water vapour

While in flight, an AMDAR-equipped aircraft reports the real-time meteorological variables above every 3-10 minutes.

This AMDAR animation illustrates how frequently AMDAR instruments transmit data during the various stages of flight.

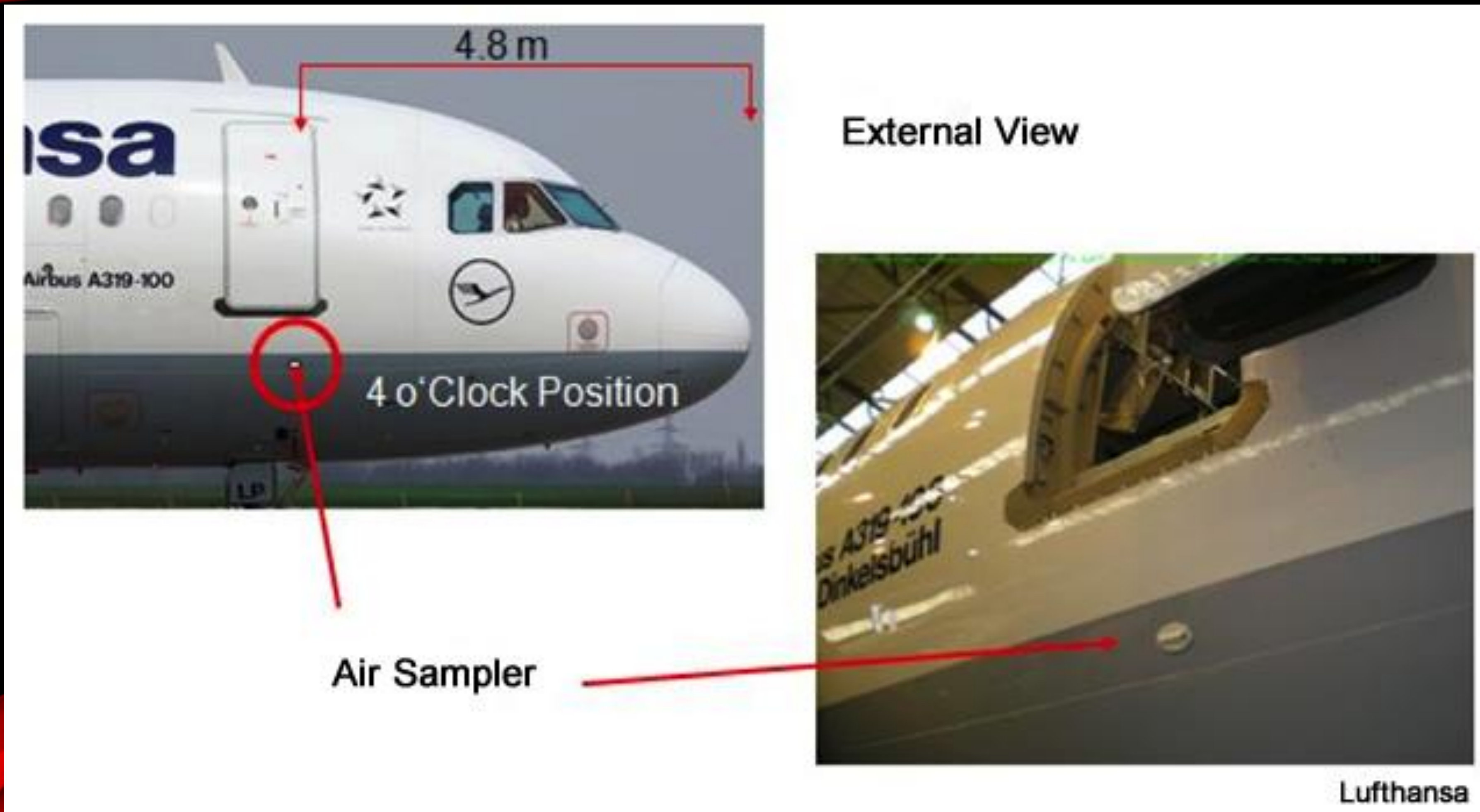
AMDAR can measure or derive the following meteorological parameters with very accurate time, pressure altitude, and latitude and longitude coordinates:

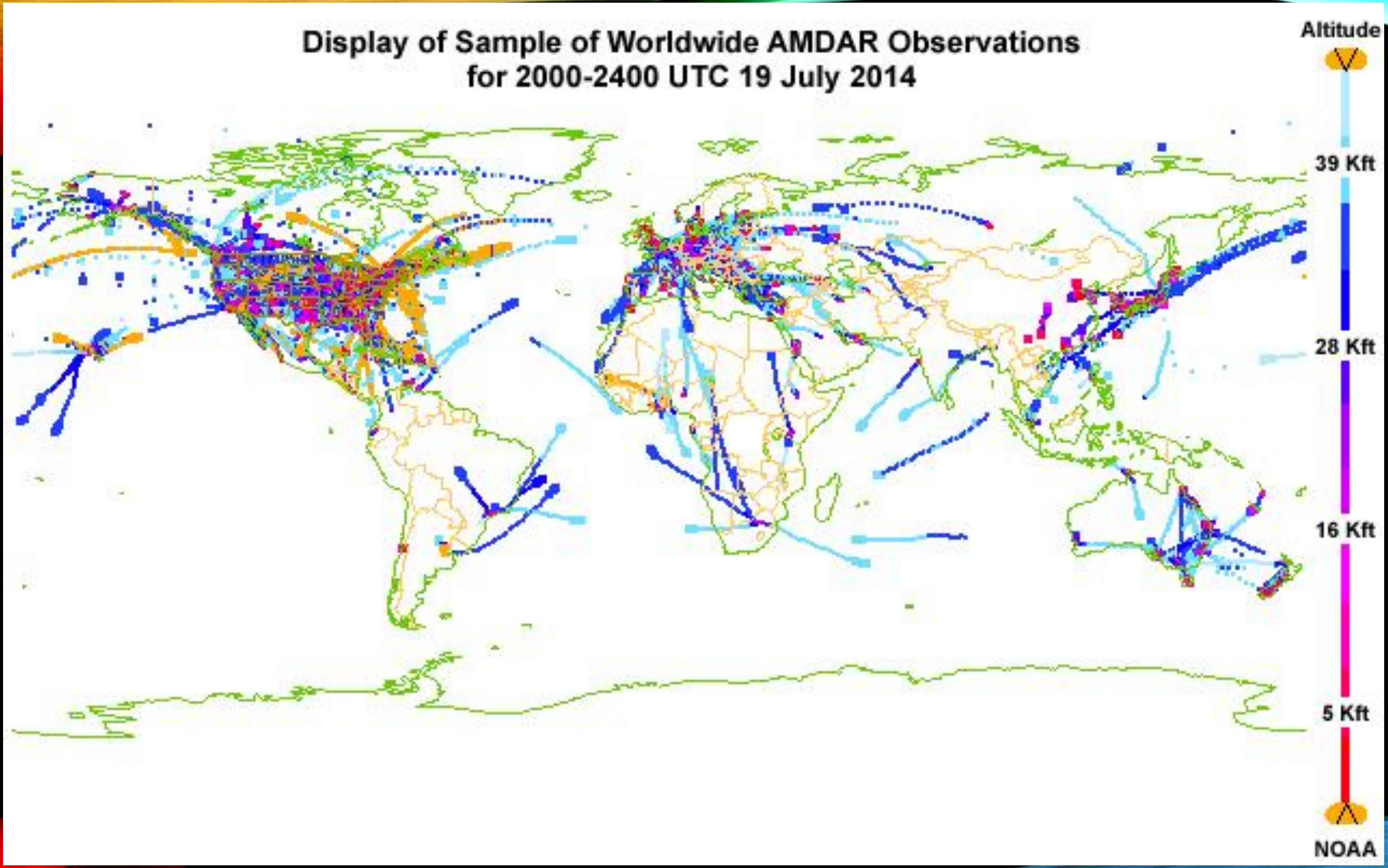
Additional non-meteorological parameters that can be reported:

- Icing indication including accreting or not accreting (pending)
- Departure and destination airport
- Aircraft roll angle
- Flight identifier

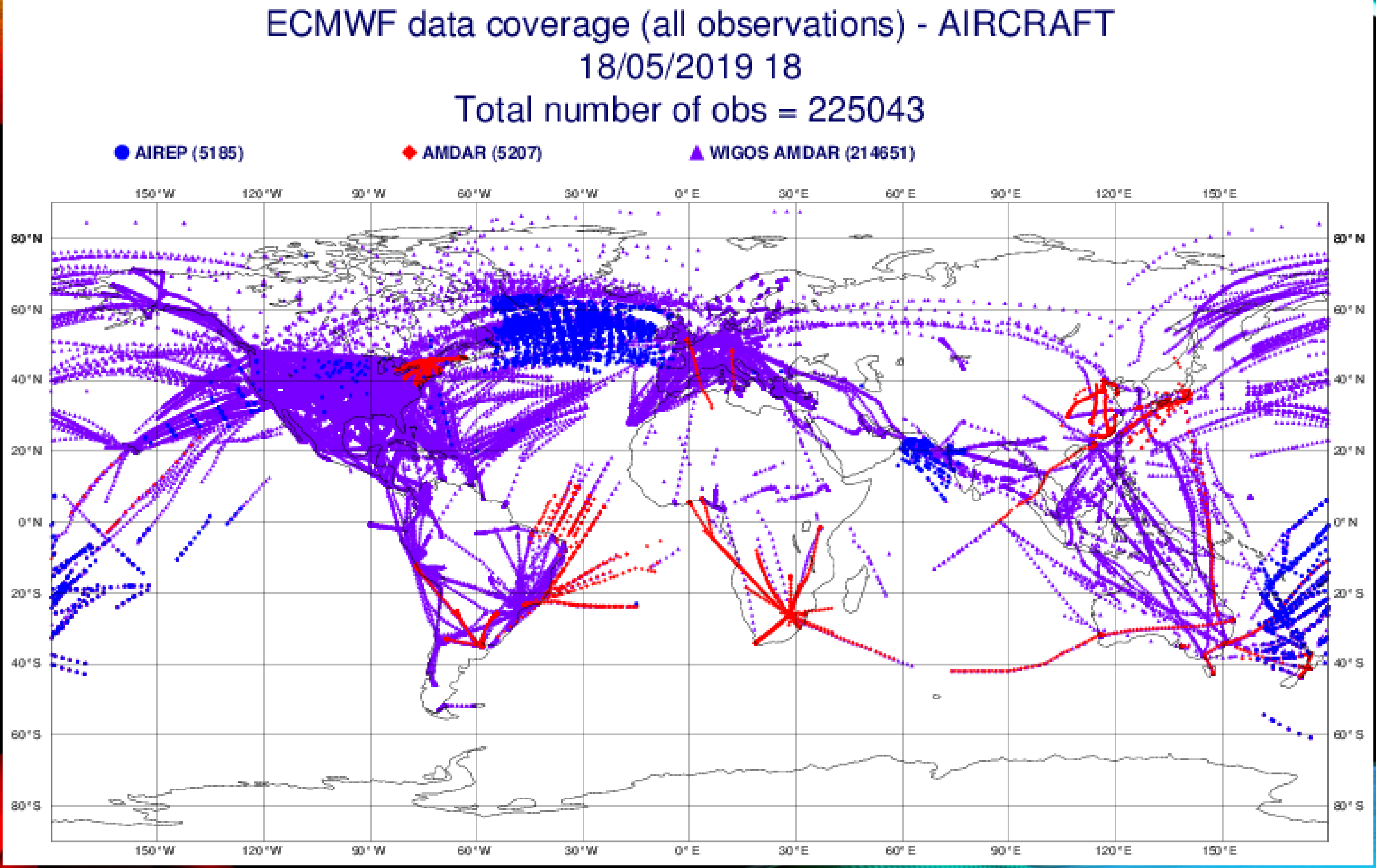
The AMDAR Communications System

WMO/The COMET Program

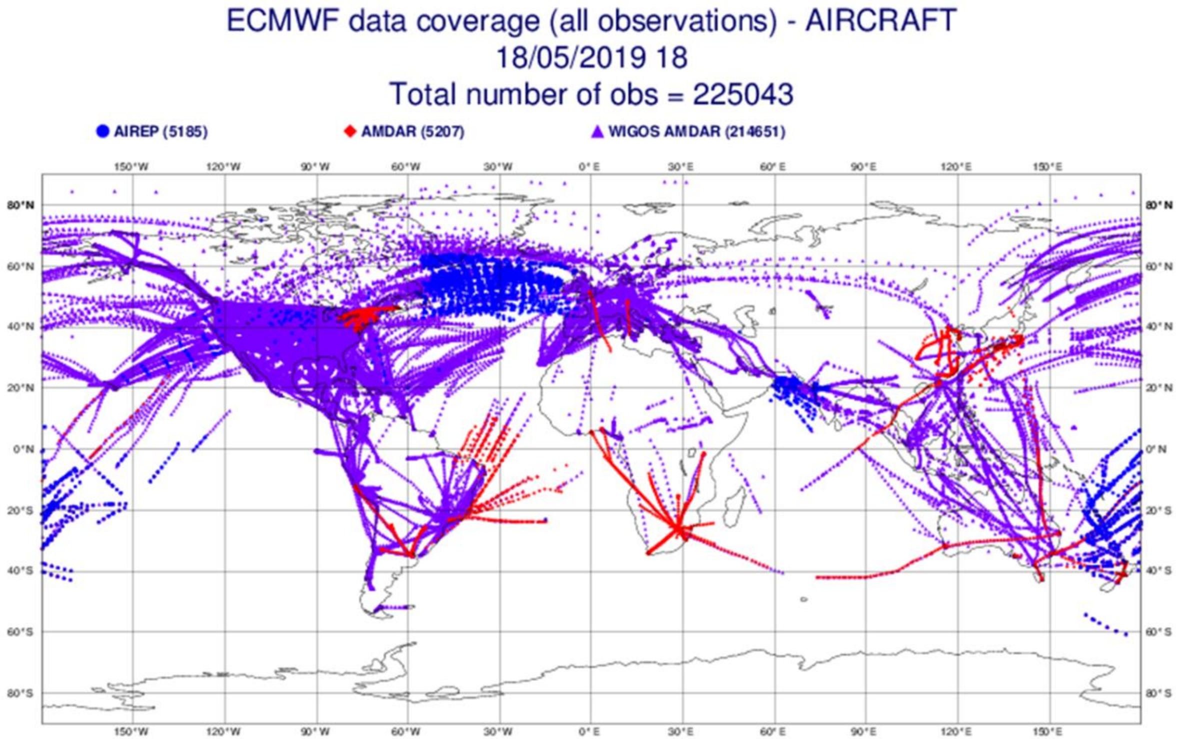

4.8 m
External View
Airbus A319-100
4 o'Clock Position
Air Sampler
Lufthansa



One disadvantage is that most of the reports come from a narrow range of cruising altitudes. However, the ascents and descents near airports are very valuable for local forecasting.



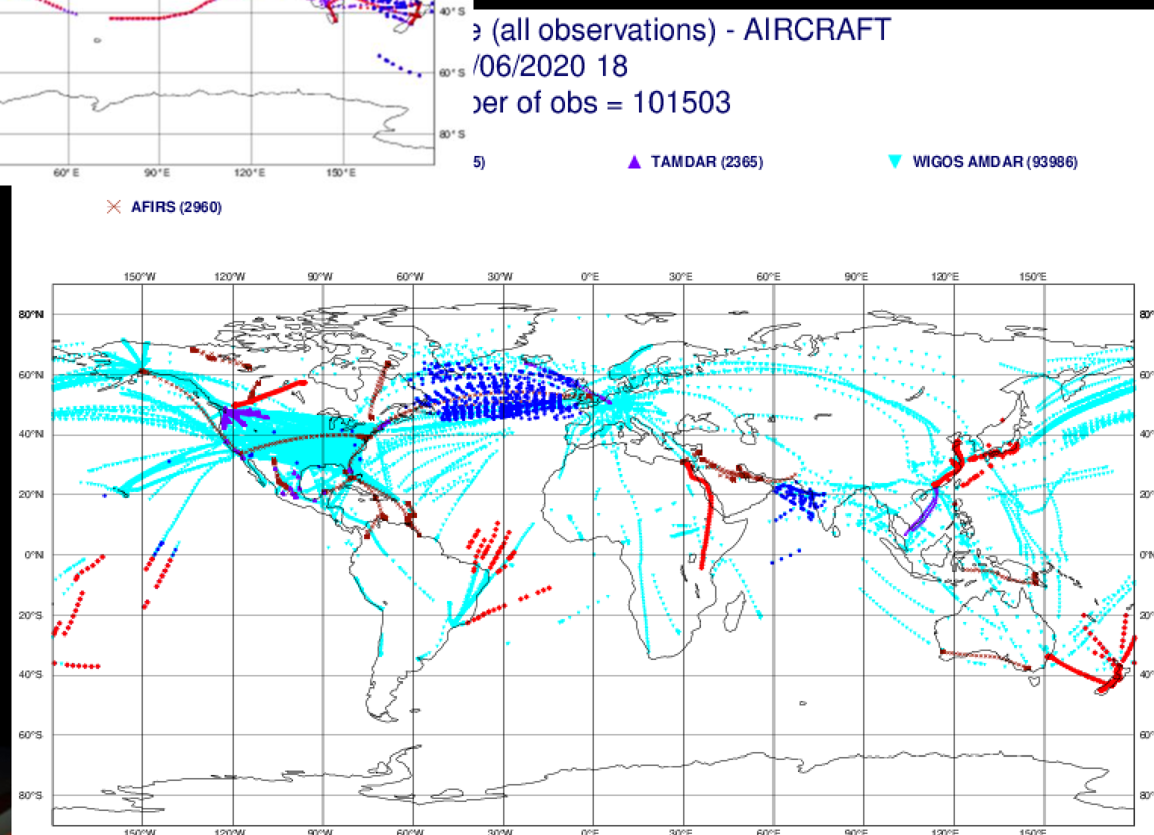
4 am Melbourne time

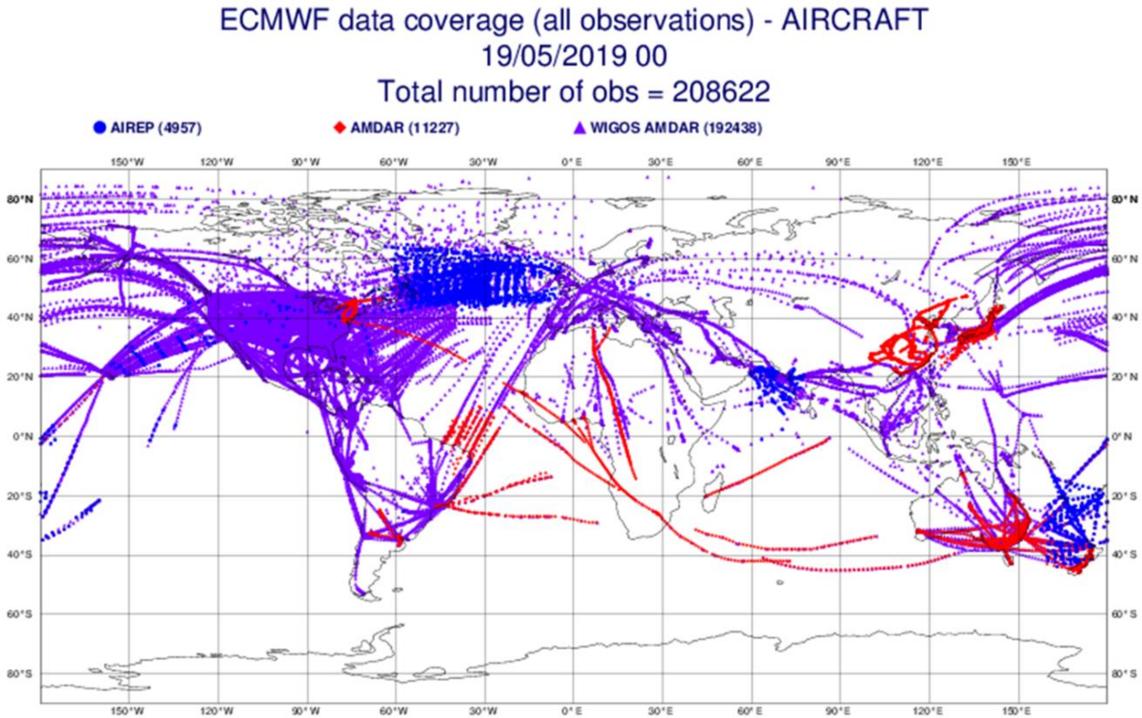


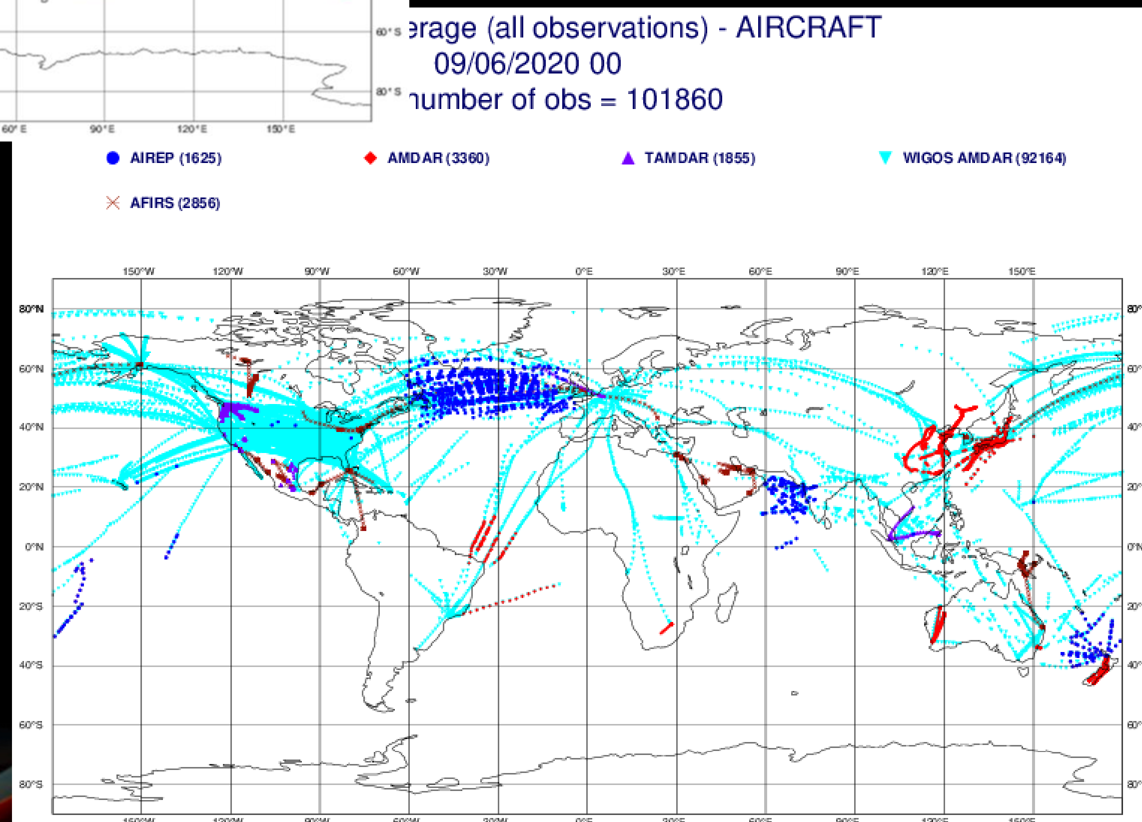
2019

4 am AEST

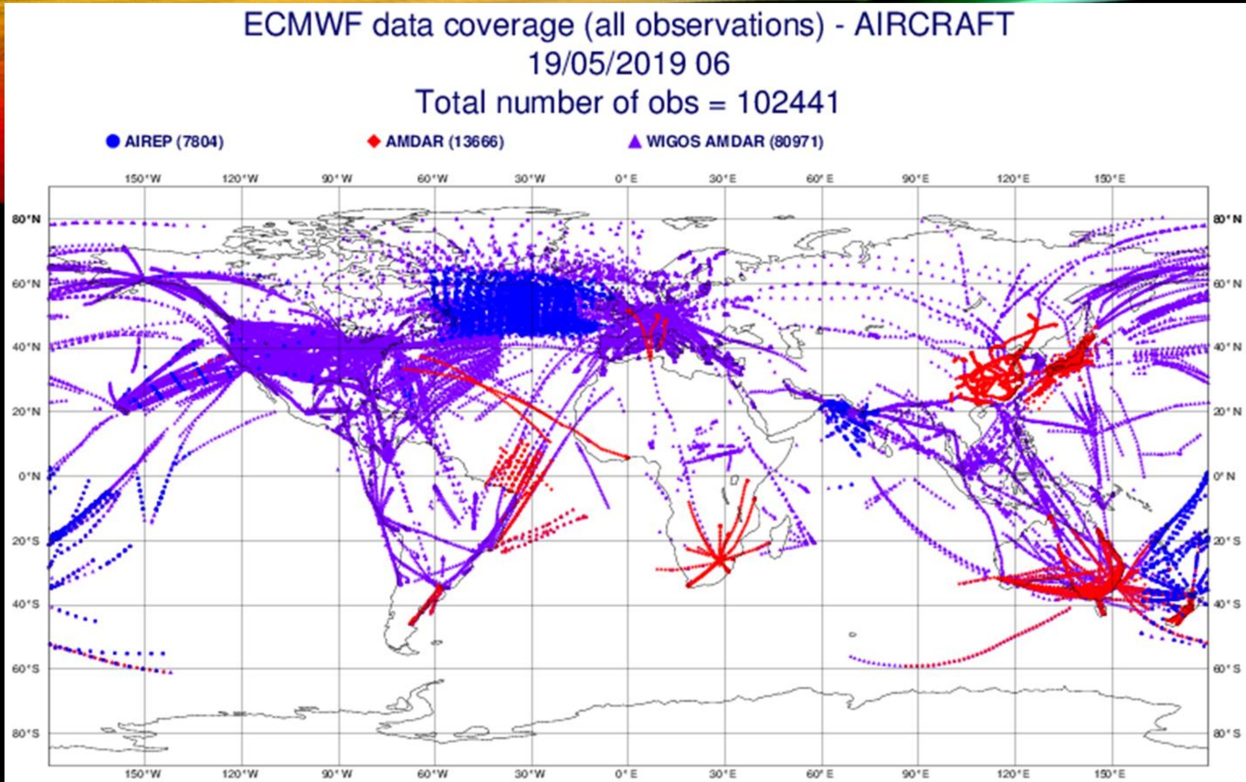
2020

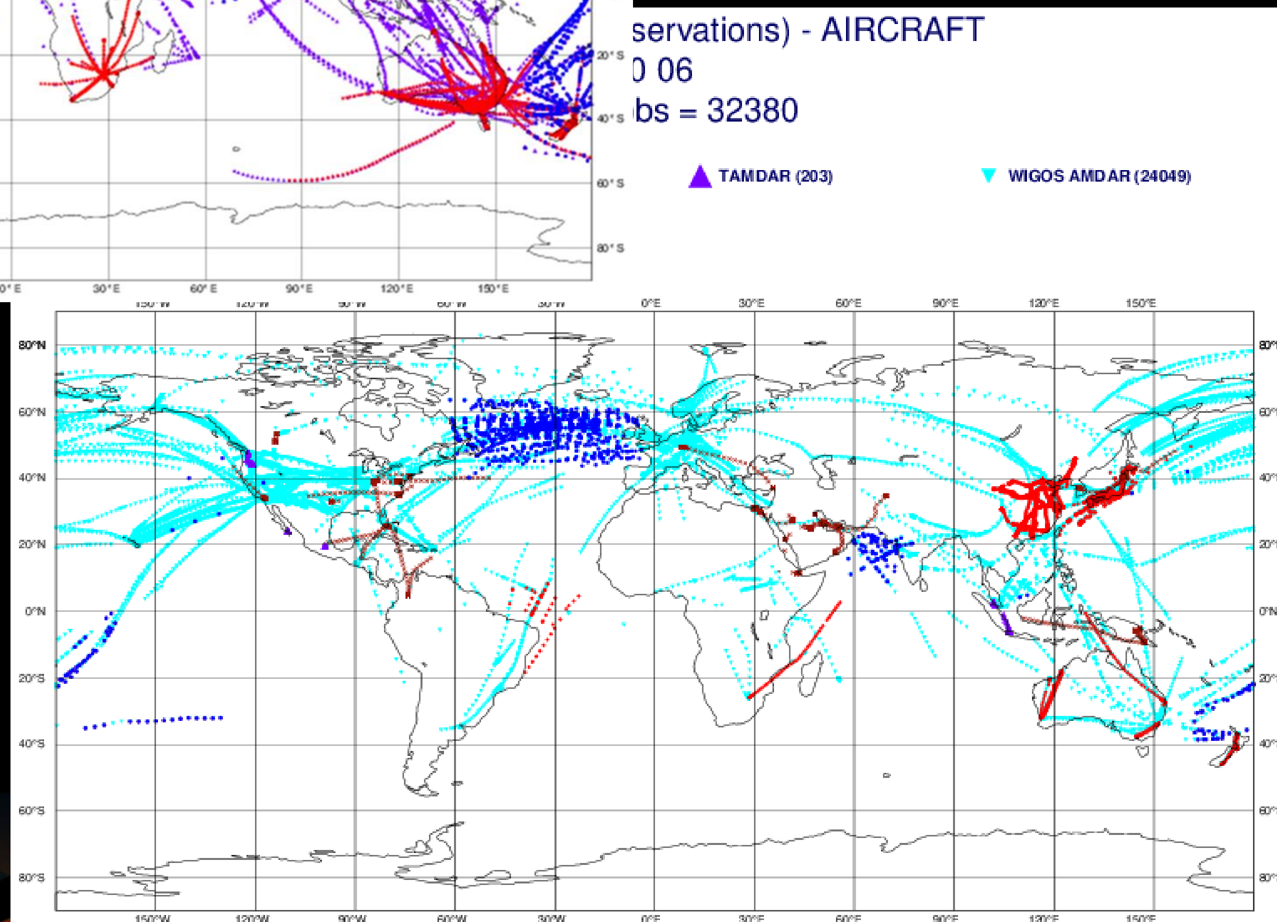



ECMWF data coverage (all observations) - AIRCRAFT
19/05/2019 00
Total number of obs = 208622
AIREP (4957)
AMDAR (11227)
WIGOS AMDAR (192438)

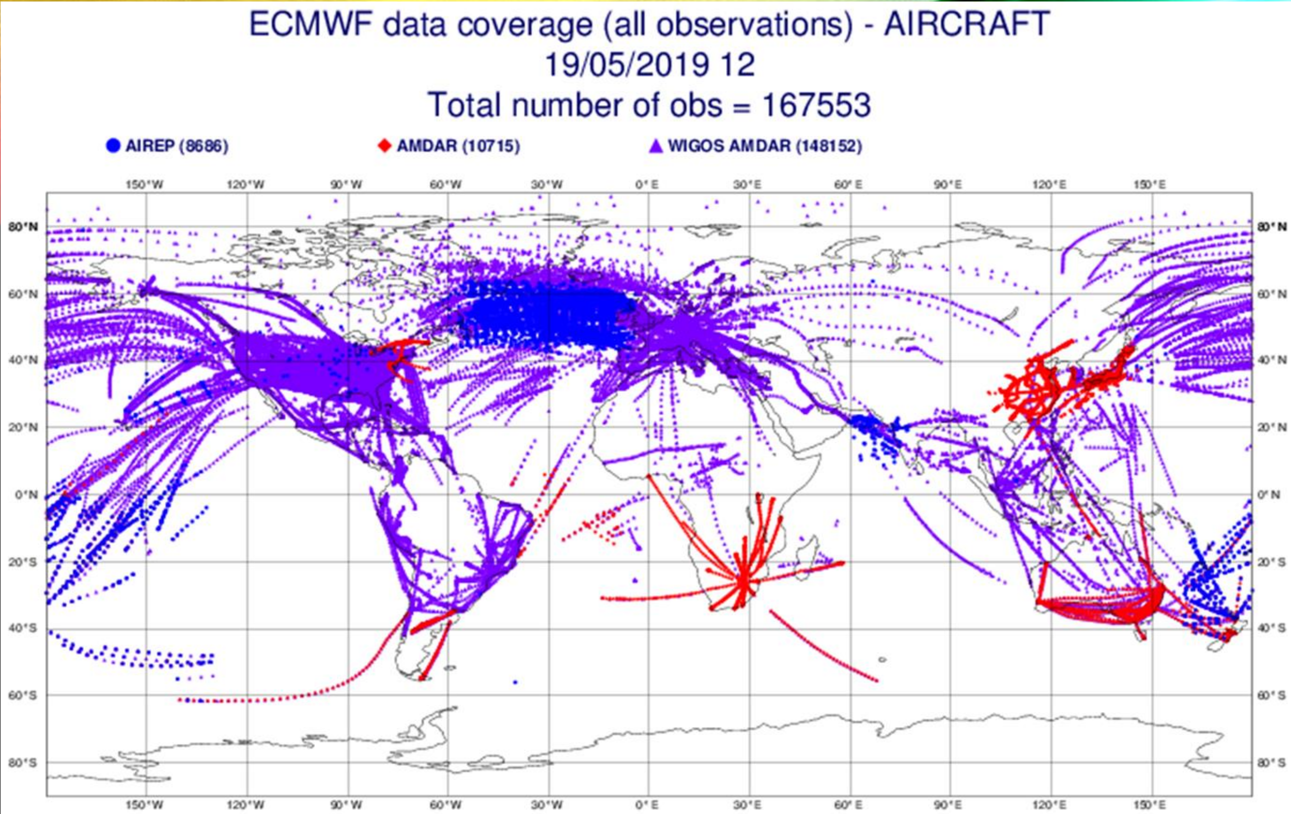

erage (all observations) - AIRCRAFT
09/06/2020 00
number of obs = 101860
AIREP (1625)
AMDAR (3360)
TAMDAR (1855)
WIGOS AMDAR (92164)
AFIRS (2856)

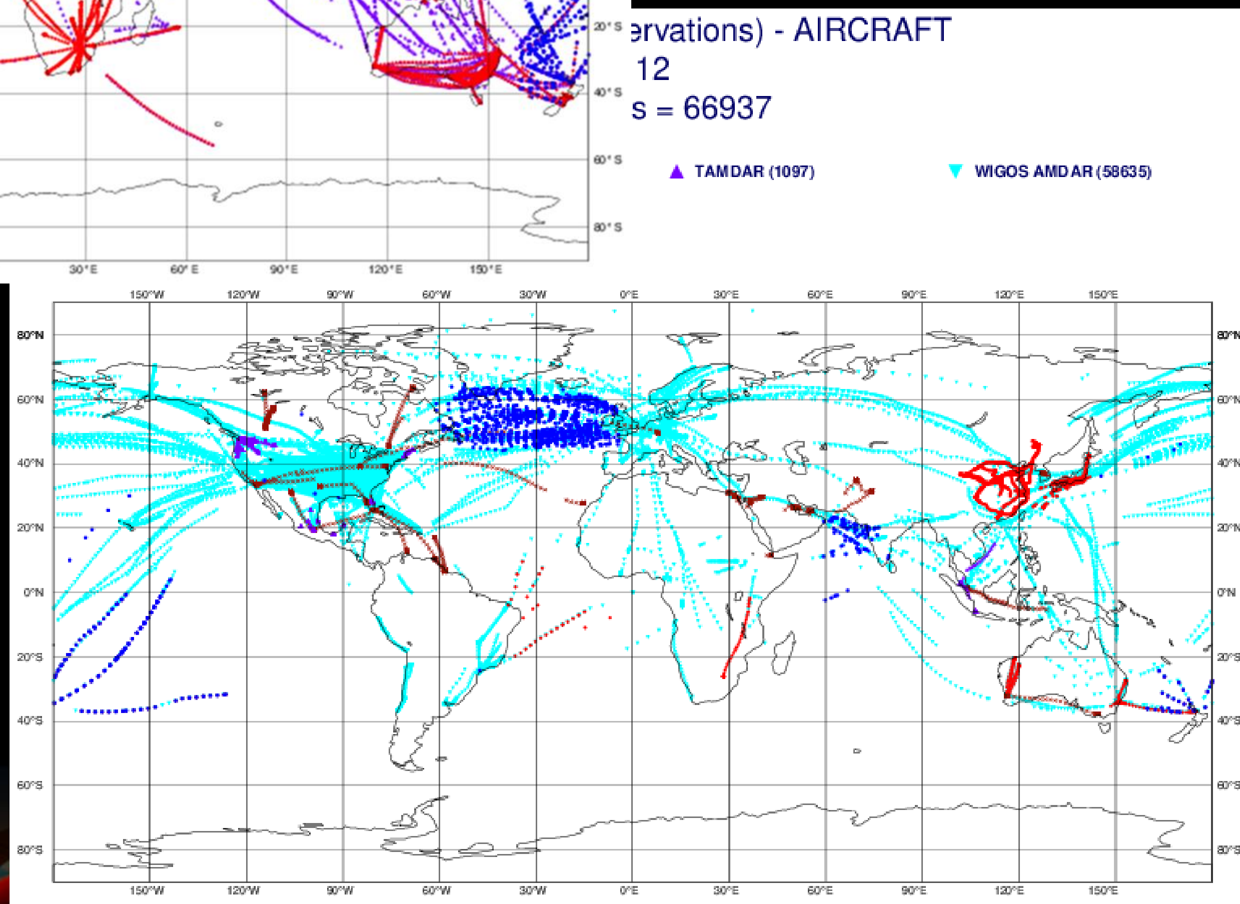
10 am AEST


ECMWF data coverage (all observations) - AIRCRAFT
19/05/2019 06
Total number of obs = 102441
AIREP (7804)
AMDAR (13666)
WIGOS AMDAR (80971)

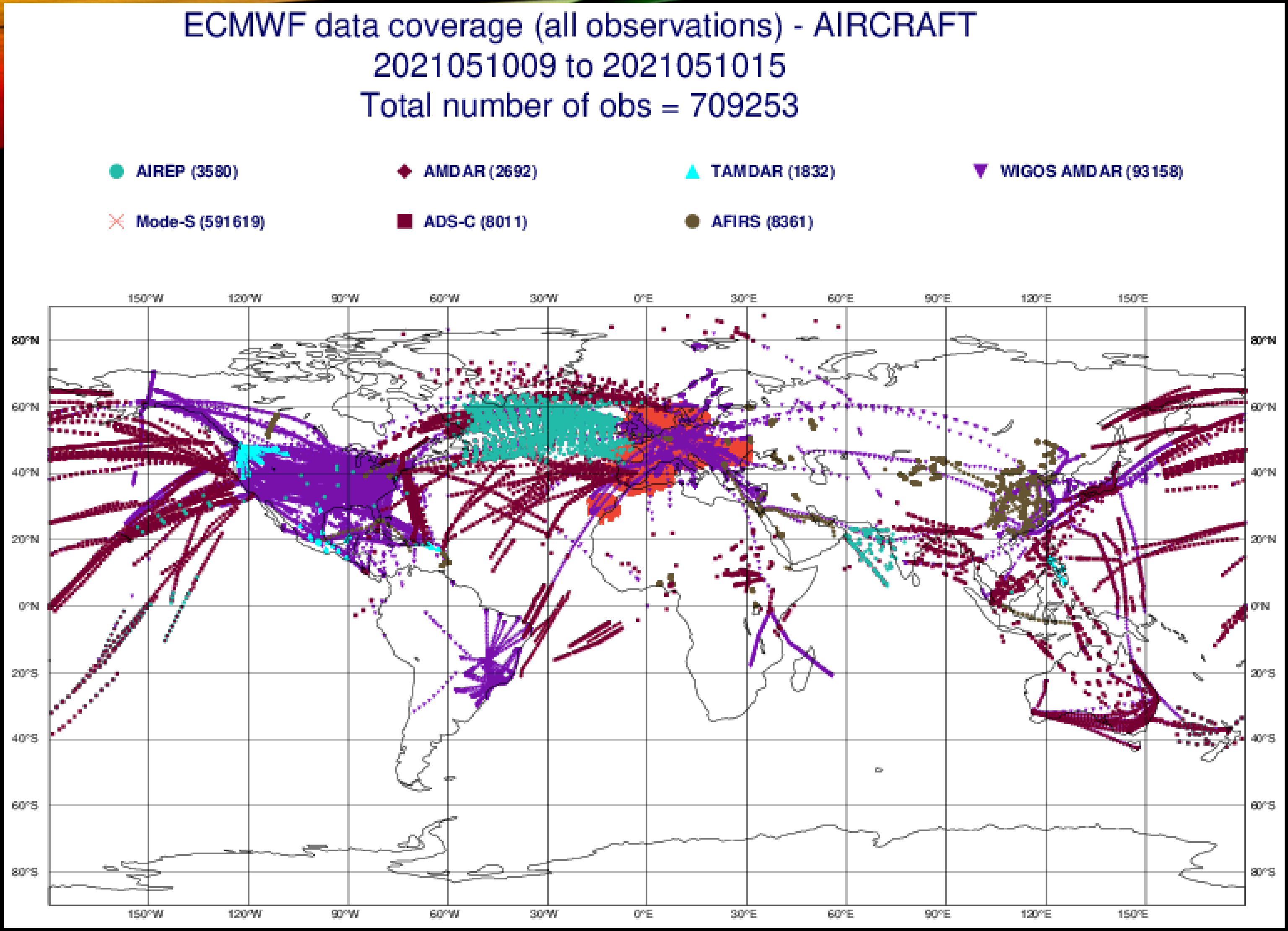

servations) - AIRCRAFT
0 06
bs = 32380
TAMDAR (203)
WIGOS AMDAR (24049)

4 pm AEST


ECMWF data coverage (all observations) - AIRCRAFT
19/05/2019 12
Total number of obs = 167553
AIREP (8686)
AMDAR (10715)
WIGOS AMDAR (148152)

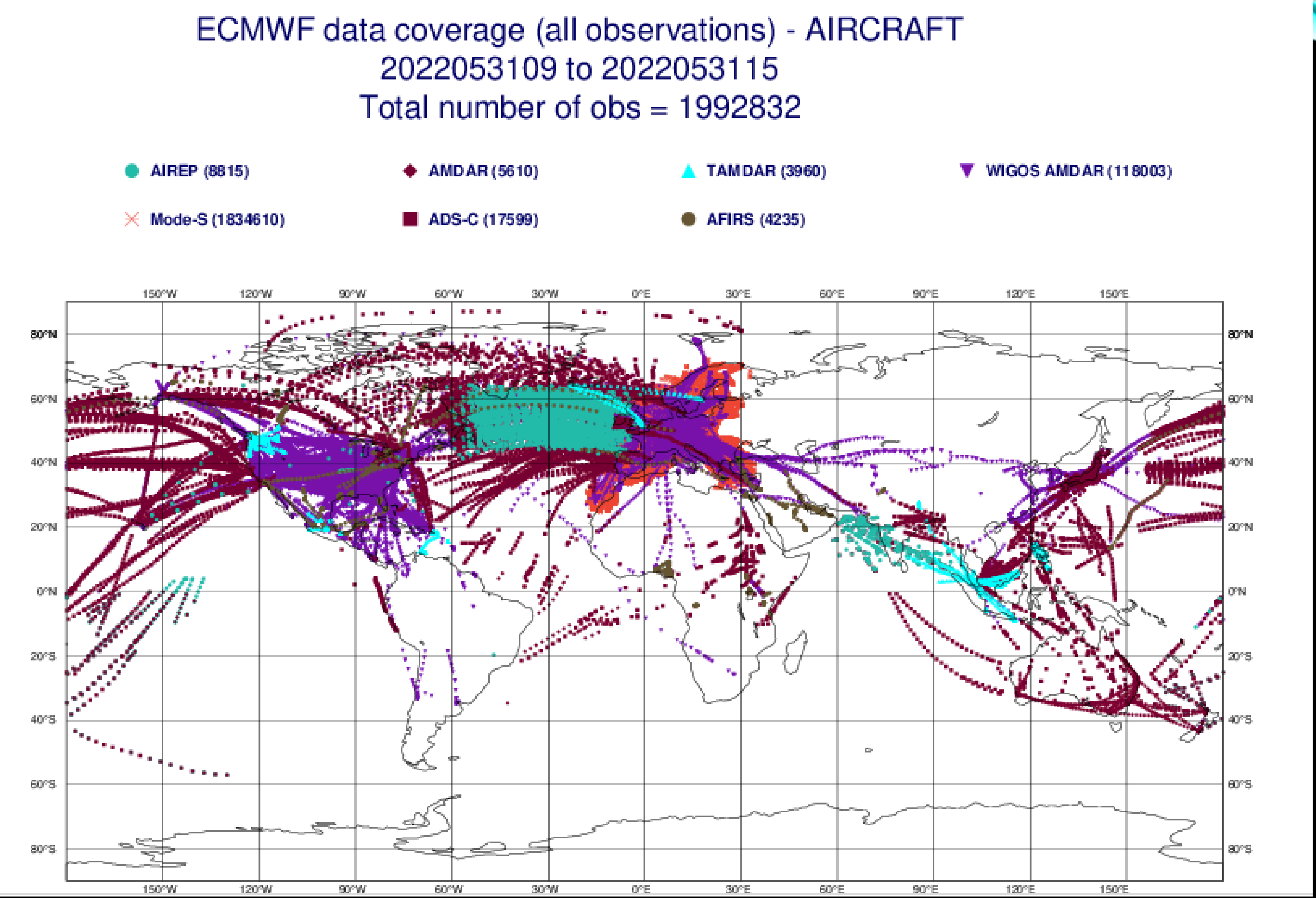

ervations) - AIRCRAFT
12
s = 66937
TAMDAR (1097)
WIGOS AMDAR (58635)

10 pm AEST

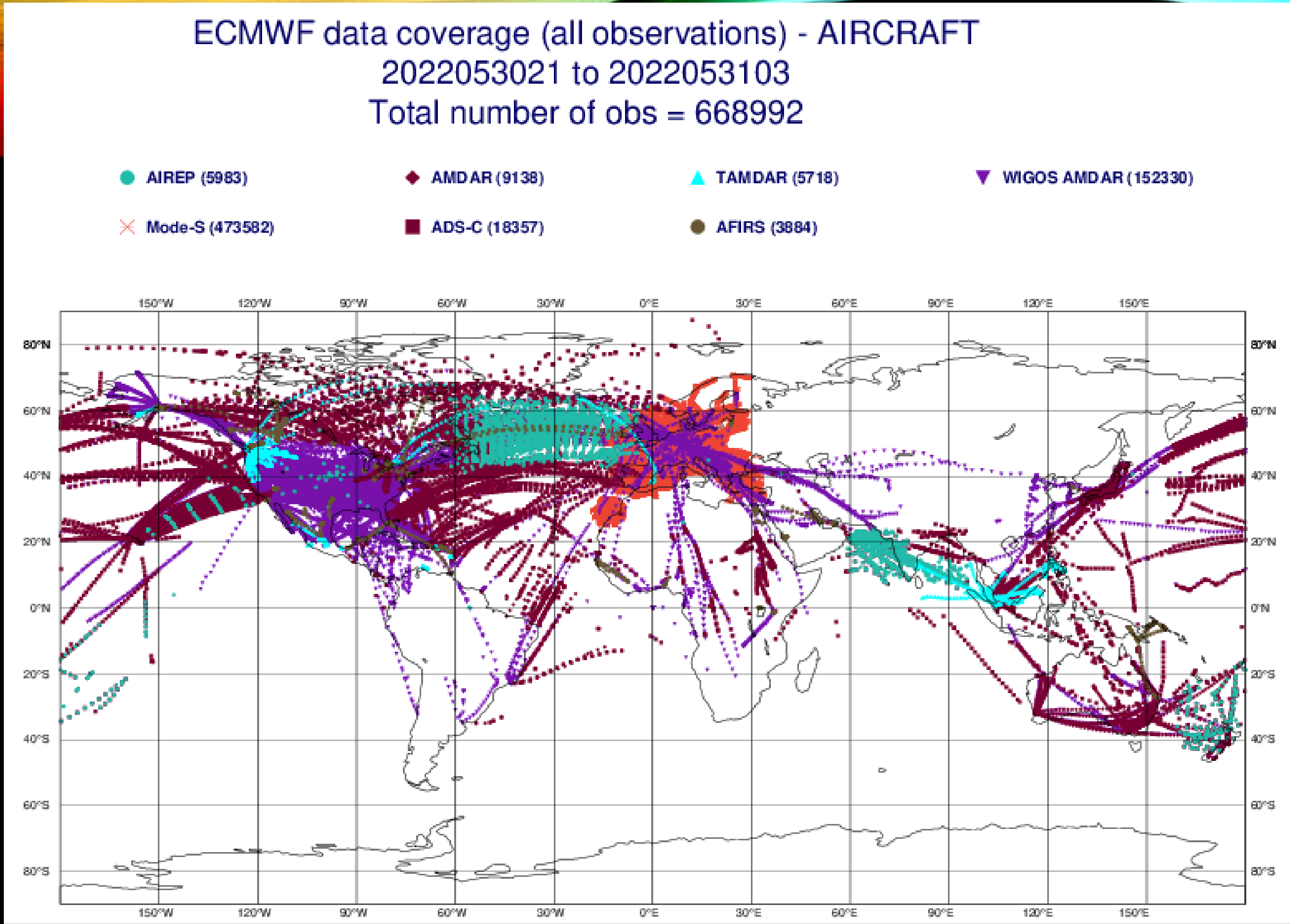


Aircraft data in the 3 hours before and after 10 pm Tuesday 10 May 2021

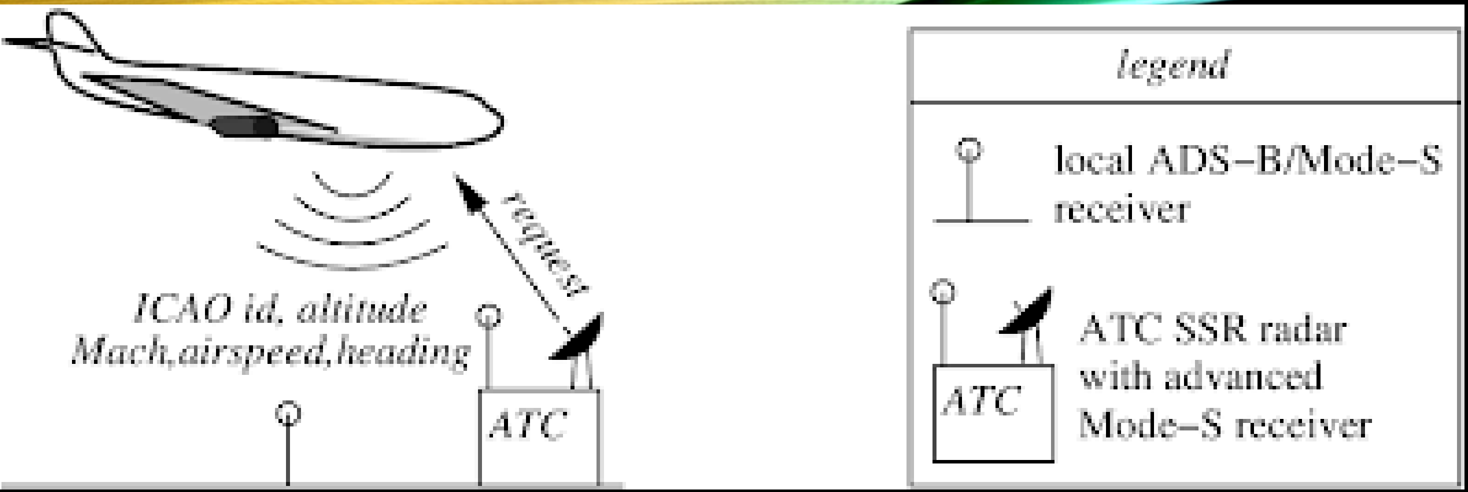
Note: the big increase in the number of reports since 2019 – Mode-S data



Aircraft data in the 3 hours before and after 10 pm Tuesday 31 May 2022



Aircraft data in the 3 hours before and after 10 am Tuesday 31 May 2021



A new development in weather observations from aircraft

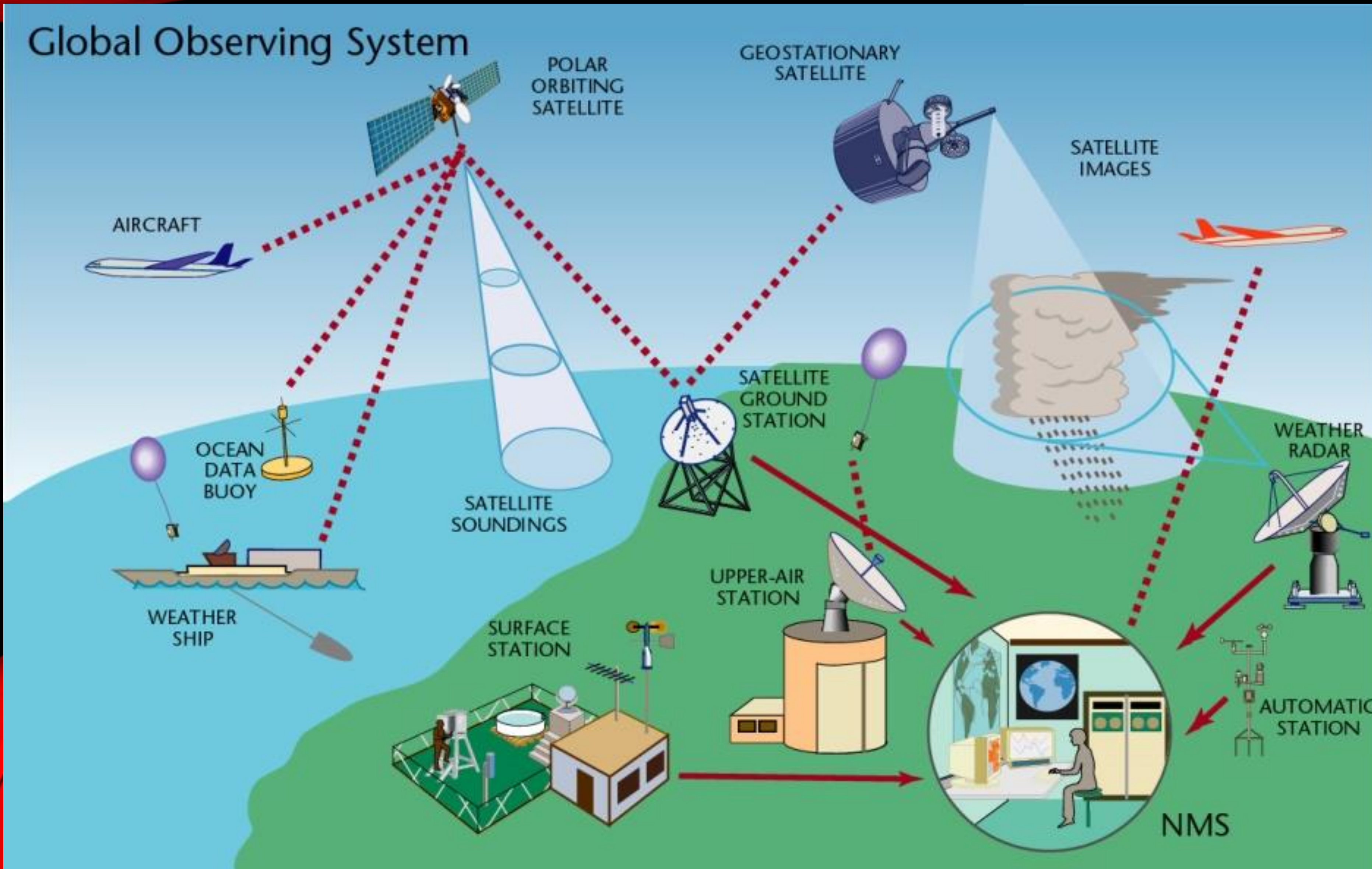
Aircraft send out data on heading, airspeed, Mach Number and altitude for air traffic control systems.

These data stem from the same source as AMDAR but are collected by the advanced tracking and ranging (TAR) radar at the airport of destination or departure (Mode-S data), rather than being transmitted from the aircraft

Wind and temperature can be deduced (temperature comes from the Mach number – related to the speed of sound)

Information from all aircraft are gathered, in contrast to AMDAR where only dedicated aircraft equipped with AMDAR software can be used.

Observing the atmosphere uses many different types of systems and measurements



Elements of the Global Observing System

Atmospheric Motion Vectors (satellite-derived winds)

(Infrared, Visible and Water Vapour)

Atmospheric Motion Vectors are derived using a sequence of images. Using 3 images features targeted in the second image (cirrus cloud edges, small cumulus clouds etc.) are tracked in the first and third images, giving two estimates of wind speed. These two are averaged to get a better estimate.

Atmospheric Motion Vectors (satellite-derived winds)

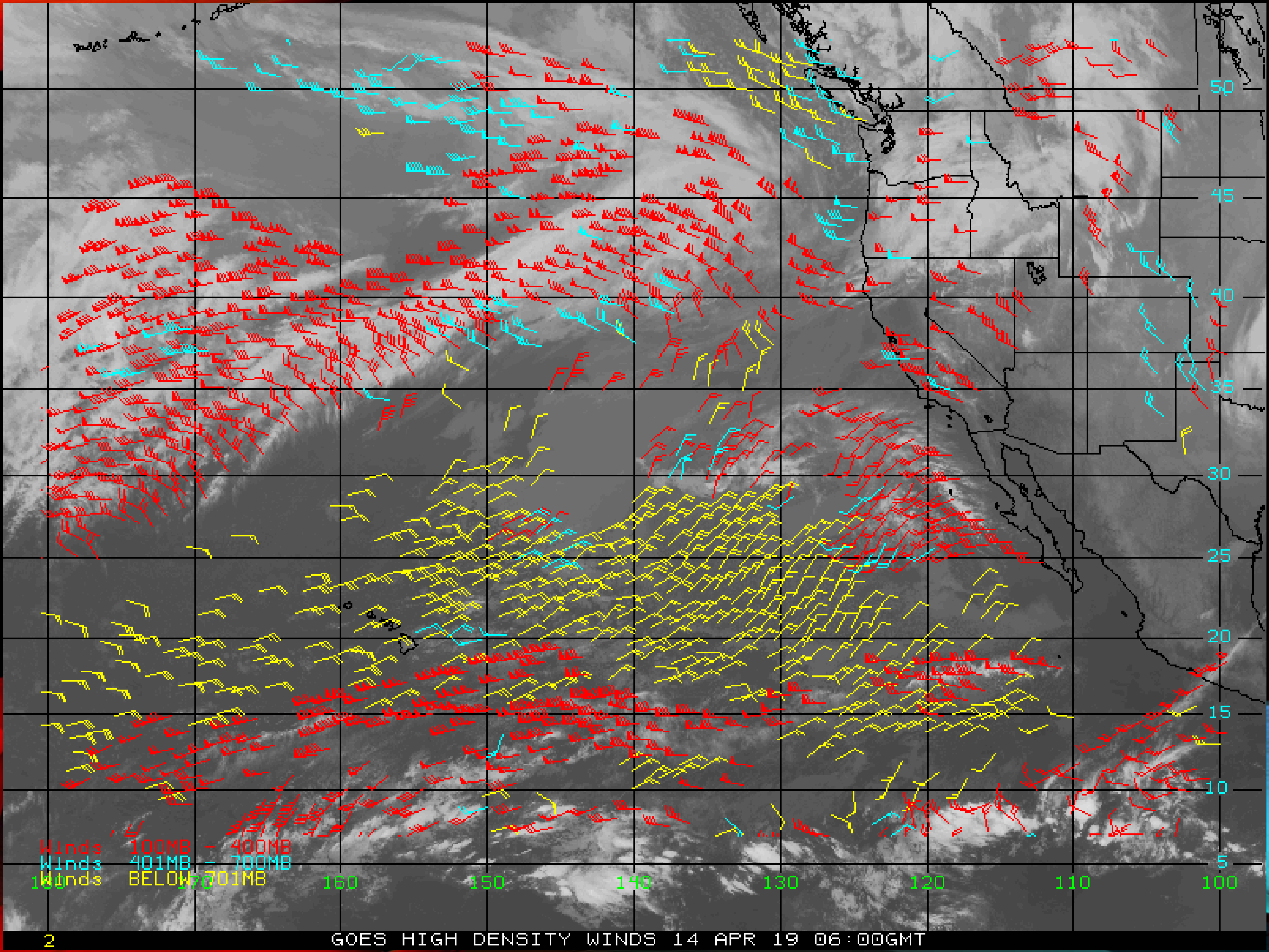
(Infrared, Visible and Water Vapour)

The next step is to assign a **height** for this estimated wind. For infrared measurements, the measured temperature is compared with a collocated numerical model temperature profile.

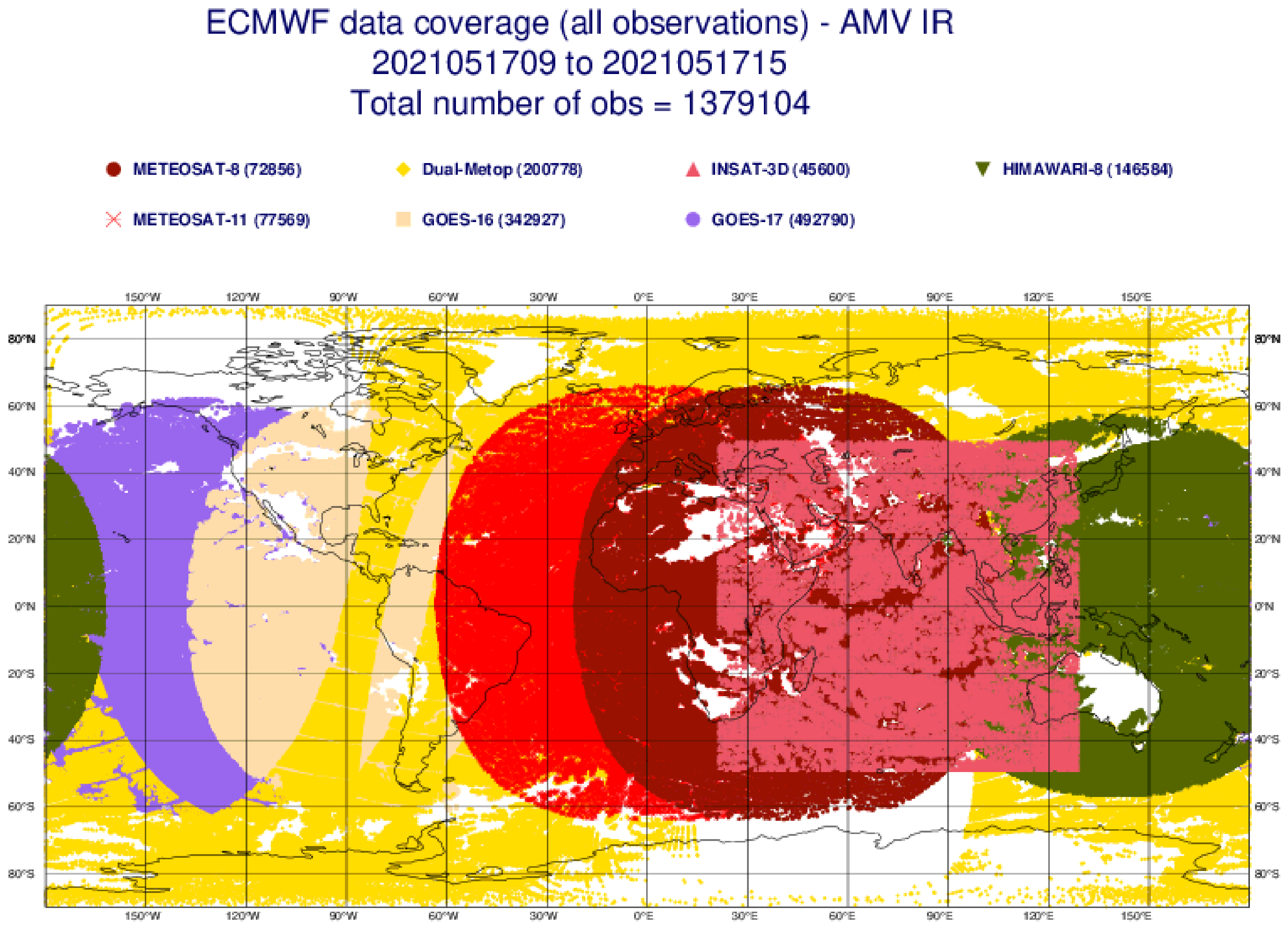
For visible channel measurements – assigning the height depends on knowing the cloud top height, often by comparing with infrared measurements for the same location.

While the concept is simple, the procedure is rather complex. In fact, it took several decades before satellite derived winds were accurate enough to be incorporated into weather forecasts.

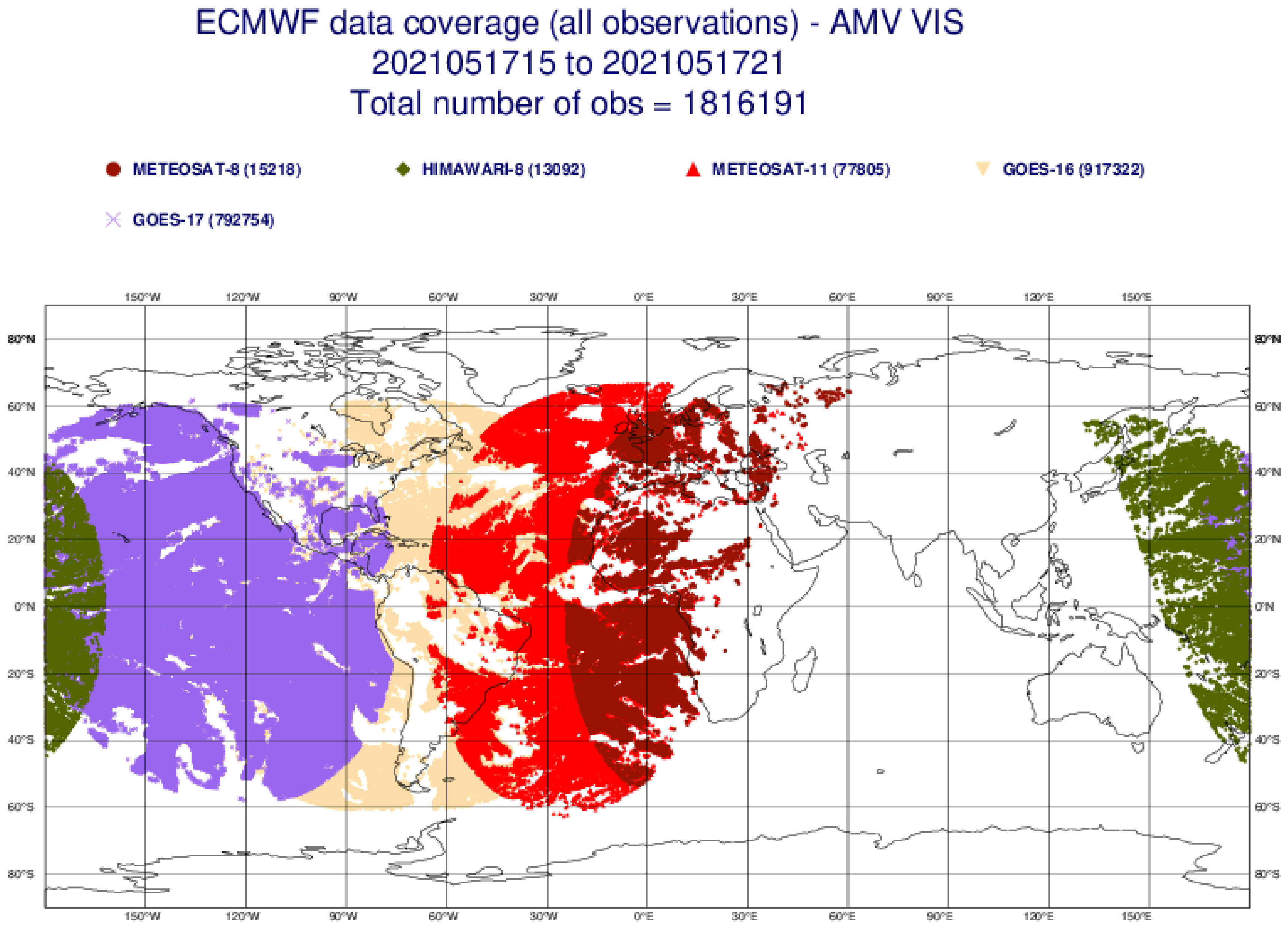
Atmospheric Motion Vectors (satellite-derived winds)



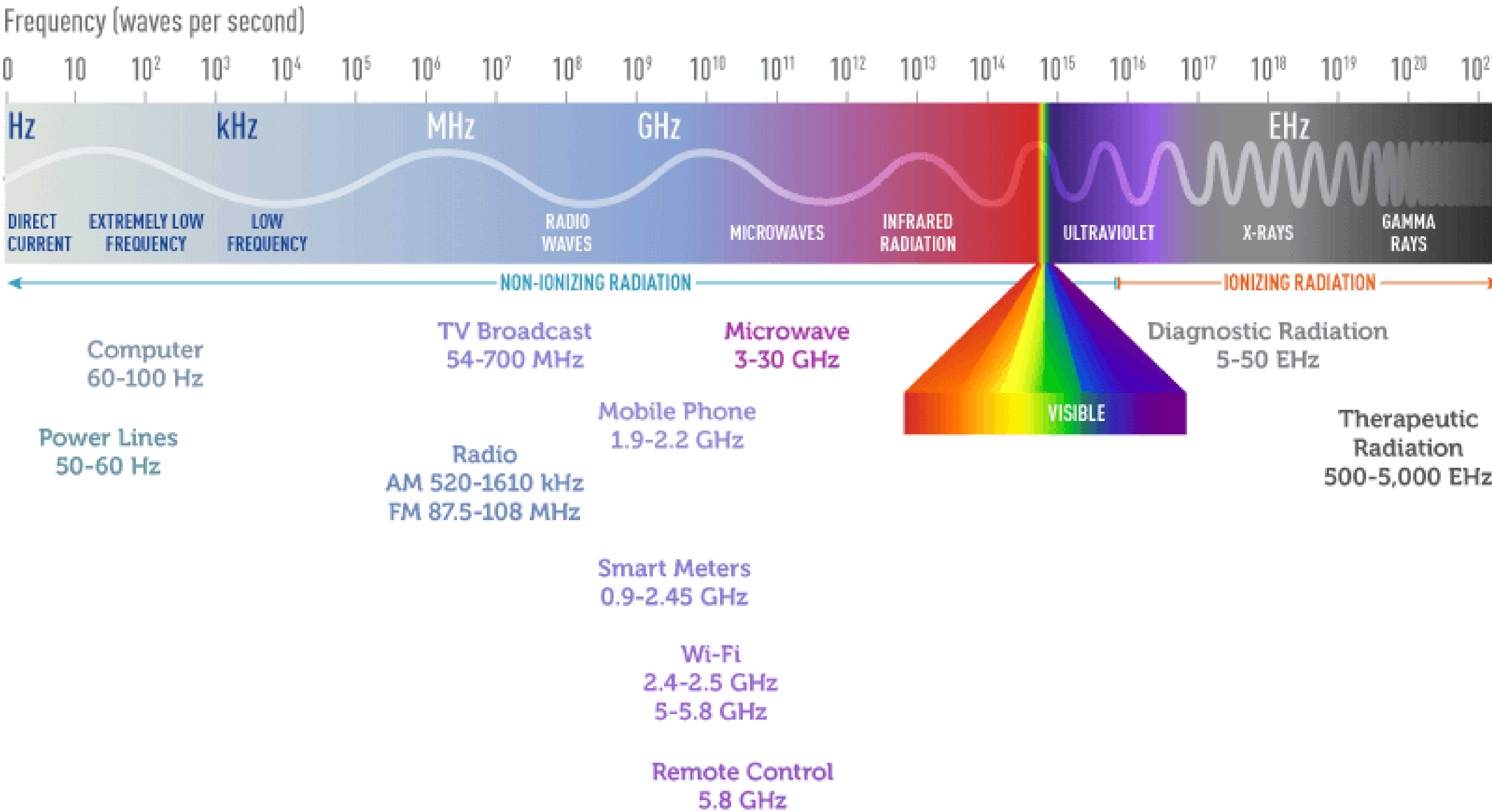
Atmospheric Motion Vectors (satellite-derived winds) - **Infrared**



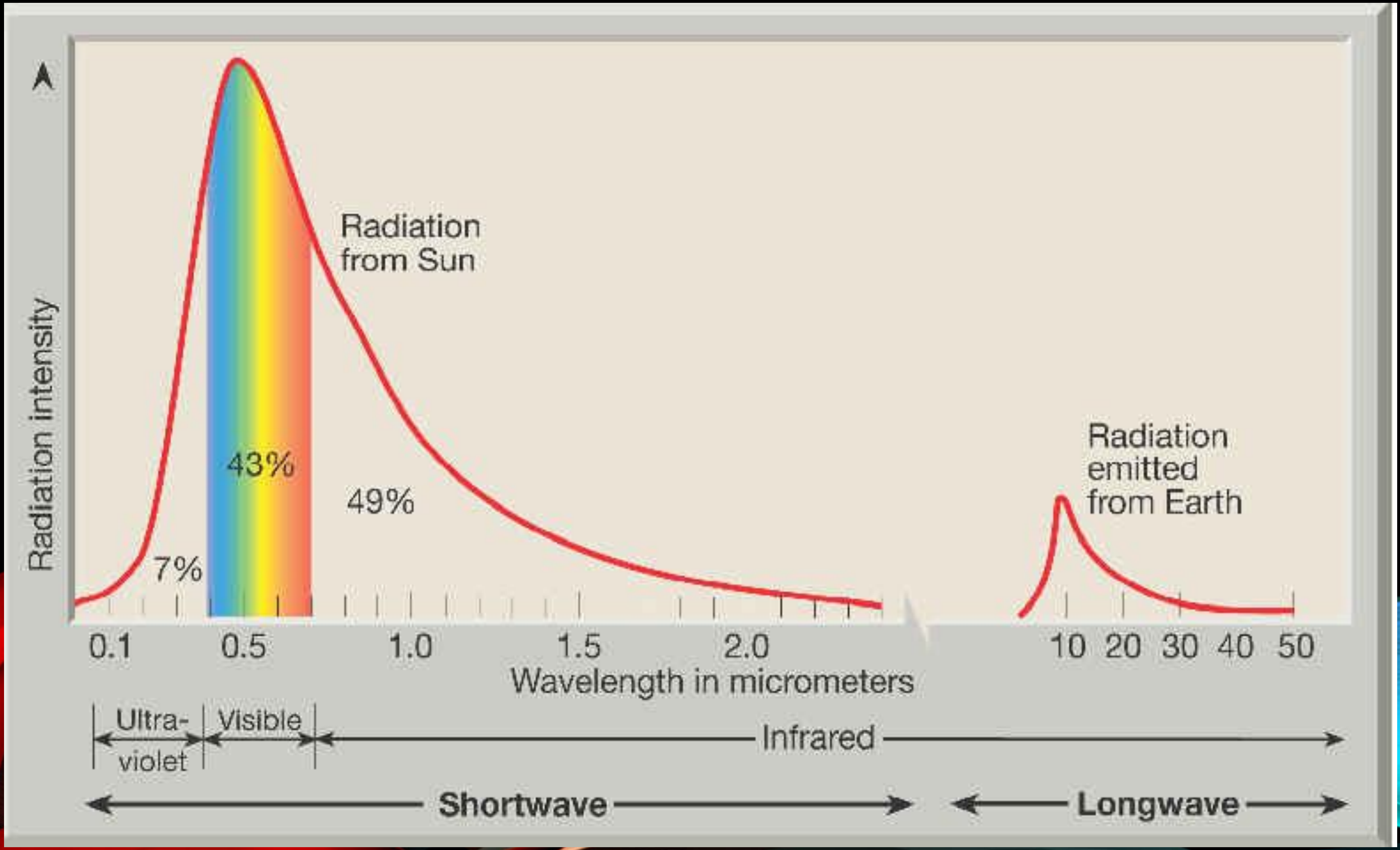
Atmospheric Motion Vectors (satellite-derived winds) - **Visible**

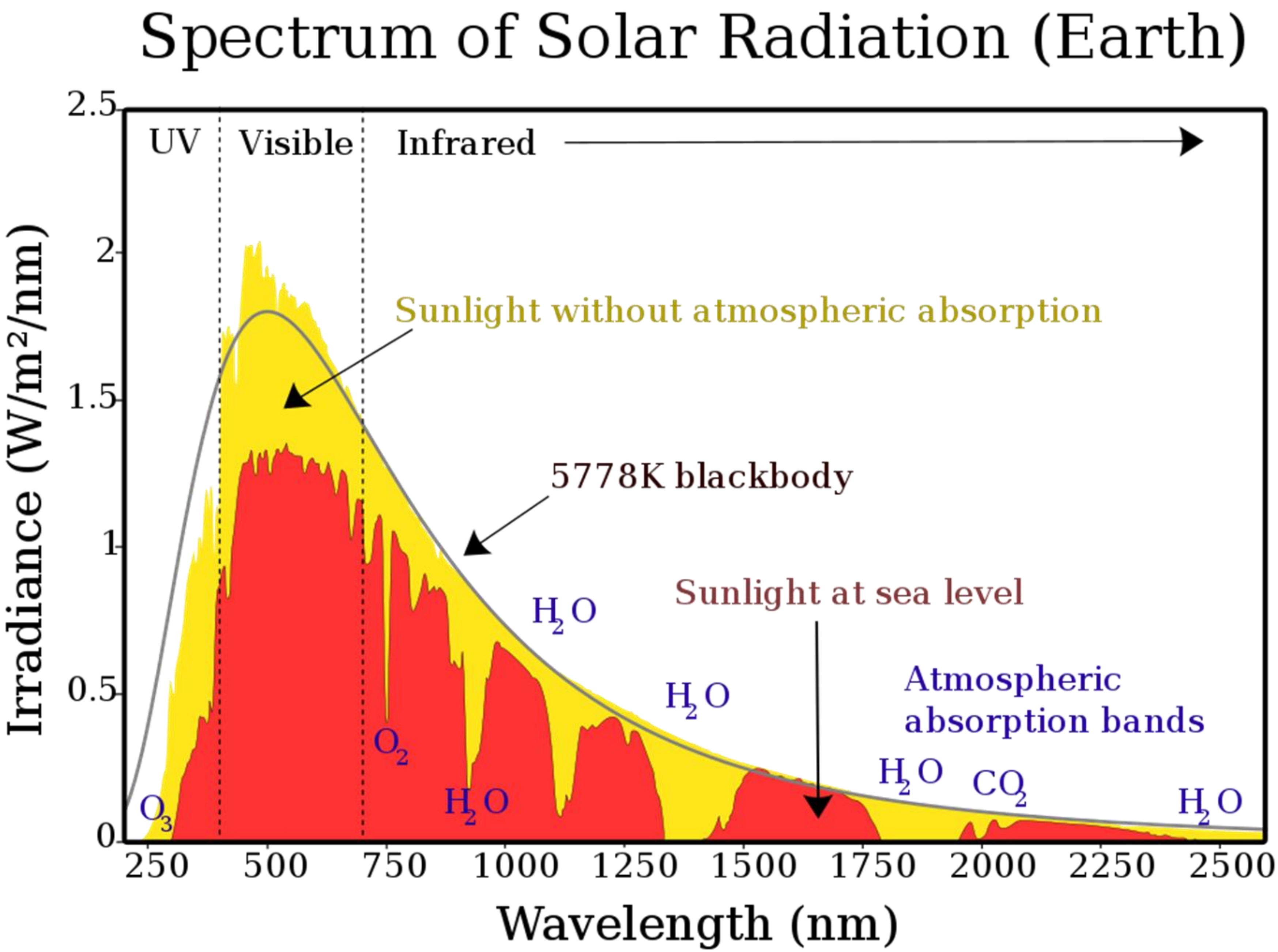


ELECTROMAGNETIC SPECTRUM

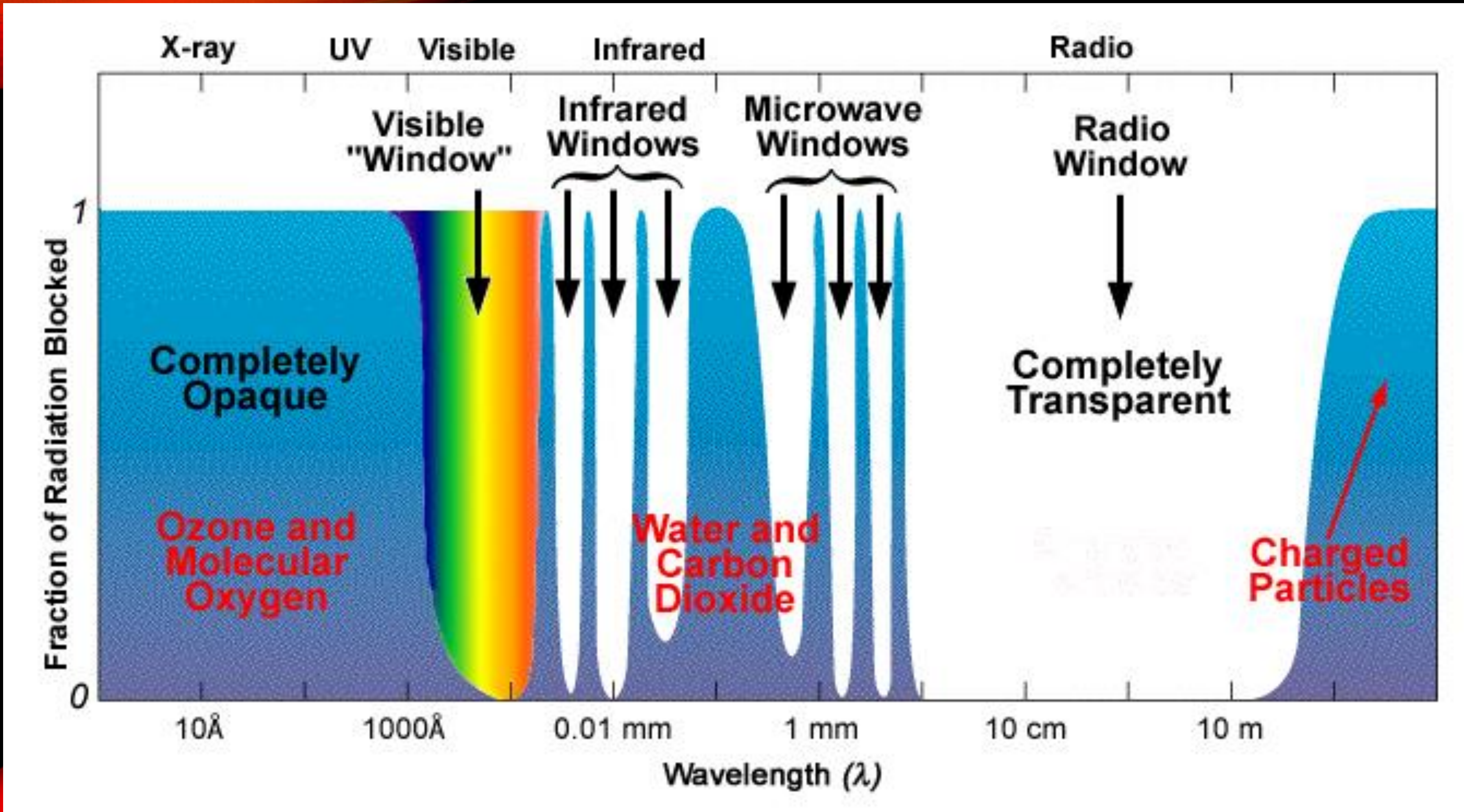


The Earth's energy budget – inward from the sun and outwards from the Earth

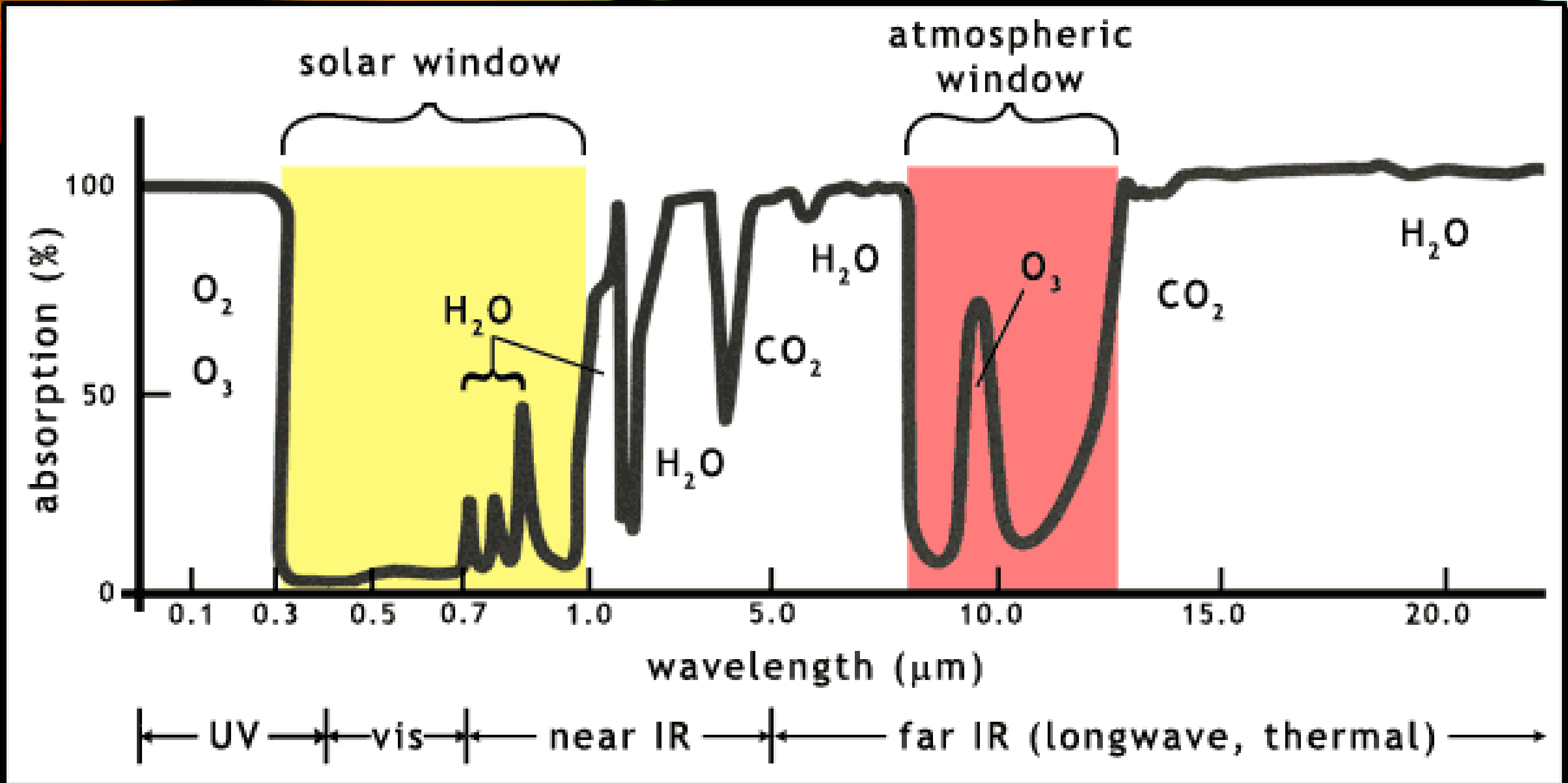




Spectrum of Solar Radiation (Earth)
UV
Visible
Infrared
Sunlight without atmospheric absorption
5778K blackbody
Sunlight at sea level
Atmospheric absorption bands
O_3
O_2
H_2O
H_2O
H_2O
H_2O
H_2O
CO_2
H_2O
Irradiance ($W/m^2/nm$)
0
0.5
1
1.5
2
2.5
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength (nm)



Note: The absorption bands are not as smooth as depicted.



Most visible light is able to reach the earth's surface, but the thermal (infrared) radiation from the surface at many wavelengths has to make its way through absorbing gases, except in the "atmospheric window". Most infrared satellite images are made at the wavelength of the atmospheric window. At other wavelengths the satellite sees radiation from upper levels.

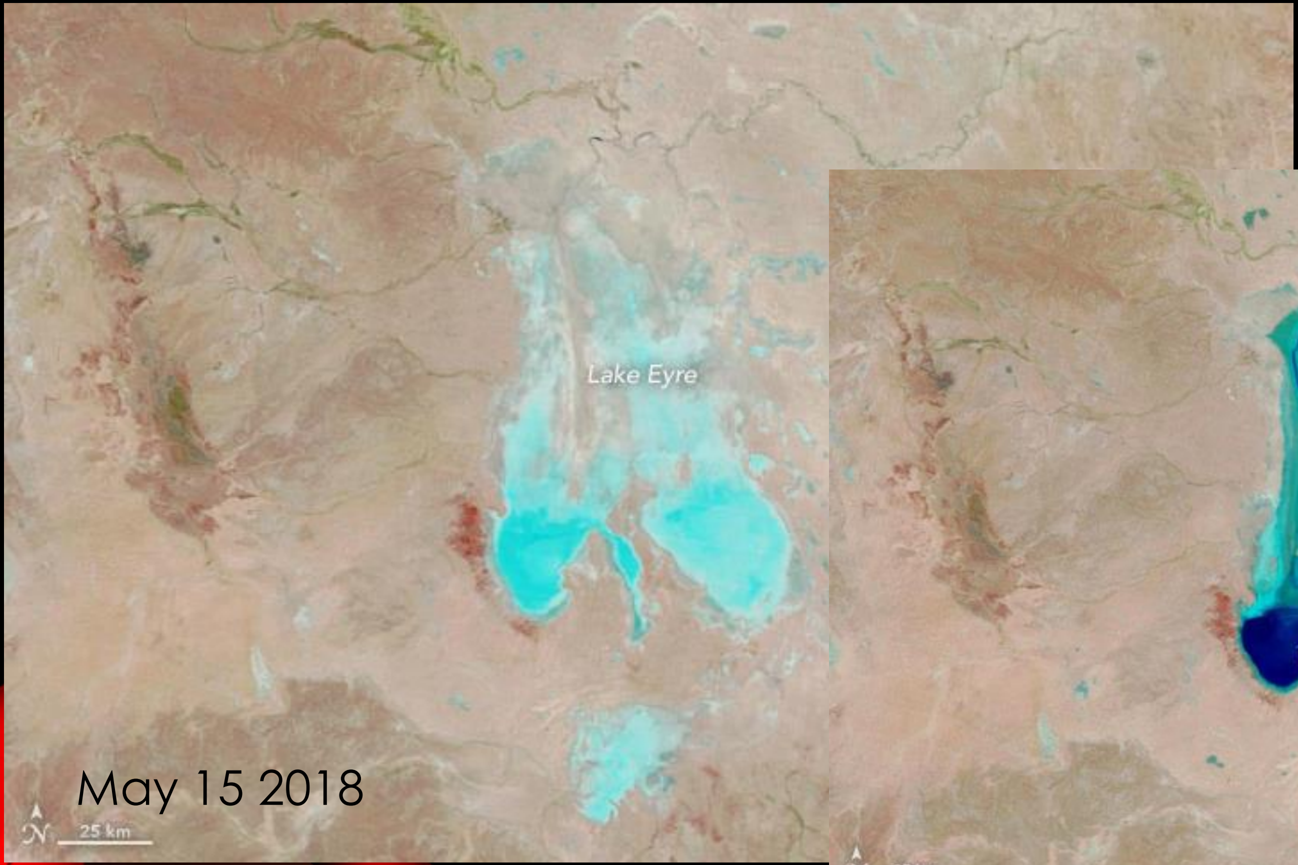
Natural-color images from Landsat 8, provide a closer view of muddy water flowing into the lake on May 5, 2019.

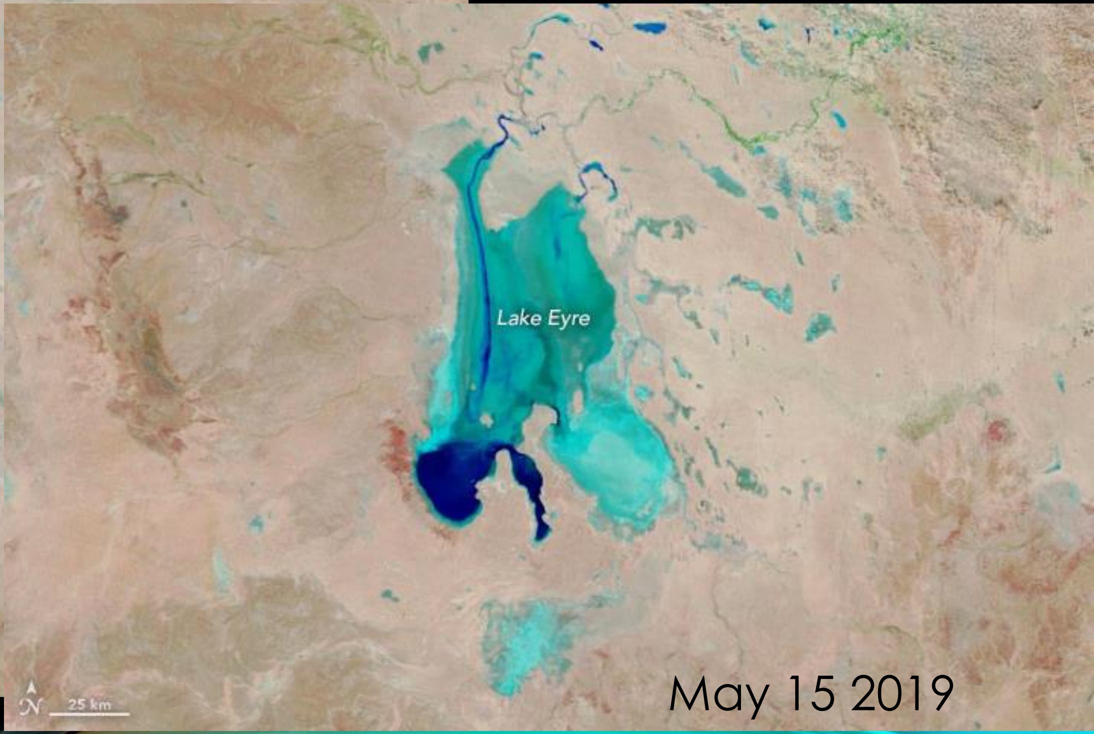
The different characteristics of the different wavelengths can be used to find information on the nature and composition of the earth, ocean and atmosphere (and other planets and their moons).

These false-color images were composed from a combination of infrared and visible light from the MODIS satellite operated by NASA (bands 7-2-1).

Water appears dark and light blue; bare ground is brown; and vegetation is bright green. This band combination makes it easier to see where water is present.

Satellite images of the filling of Kati Thanda-Lake Eyre





https://earthobservatory.nasa.gov/images/145076/rare-filling-of-kati-thanda-lake-eyre?src=eoa-iotd

Specifications

Orbit: 705 km, 10:30 a.m. descending node (Terra) or 1:30 p.m. ascending node (Aqua), sun-synchronous, near-polar, circular

Scan Rate: 20.3 rpm, cross track

Swath Dimensions: 2330 km (cross track) by 10 km (along track at nadir)

Telescope: 17.78 cm diam. off-axis, afocal (collimated), with intermediate field stop

Size: 1.0 x 1.6 x 1.0 m

Weight: 228.7 kg

Power: 162.5 W (single orbit average)

Data Rate: 10.6 Mbps (peak daytime); 6.1 Mbps (orbital average)

Quantization: 12 bits

Spatial Resolution: 250 m (bands 1-2), 500 m (bands 3-7), 1000 m (bands 8-36) Design Life: 6 years

https://modis.gsfc.nasa.gov/about/specifications.php

Primary Use	Band	Bandwidth[1]
Land/Cloud/Aerosols Boundaries	1	620 - 670
	2	841 - 876
Land/Cloud/Aerosols Properties	3	459 - 479
	4	545 - 565
	5	1230 - 1250
	6	1628 - 1652
	7	2105 - 2155
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420
	9	438 - 448
	10	483 - 493
	11	526 - 536
	12	546 - 556
	13	662 - 672
	14	673 - 683
	15	743 - 753
	16	862 - 877
Atmospheric Water Vapor	17	890 - 920
	18	931 - 941
	19	915 - 965

Wavelengths in nanometres

Visible
Longer wavelengths red, shorter blue

Near Infrared

Visible

Near Infrared

Primary Use	Band	Bandwidth[1]
Surface/Cloud Temperature	20	3.660 - 3.840
	21	3.929 - 3.989
	22	3.929 - 3.989
	23	4.020 - 4.080
Atmospheric Temperature	24	4.433 - 4.498
	25	4.482 - 4.549
Cirrus Clouds Water Vapor	26	1.360 - 1.390
	27	6.535 - 6.895
	28	7.175 - 7.475
Cloud Properties	29	8.400 - 8.700
Ozone	30	9.580 - 9.880
Surface/Cloud Temperature	31	10.780 - 11.280
	32	11.770 - 12.270
Cloud Top Altitude	33	13.185 - 13.485
	34	13.485 - 13.785
	35	13.785 - 14.085
	36	14.085 - 14.385

[1] Bands 1 to 19 are in nm; Bands 20 to 36 are in µm

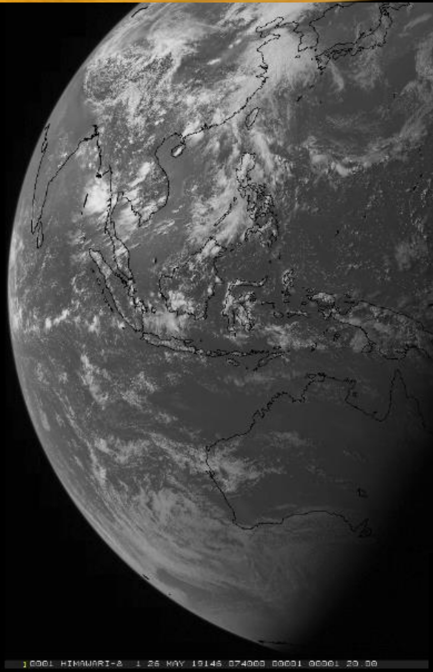
Wavelengths in microns

Near Infrared

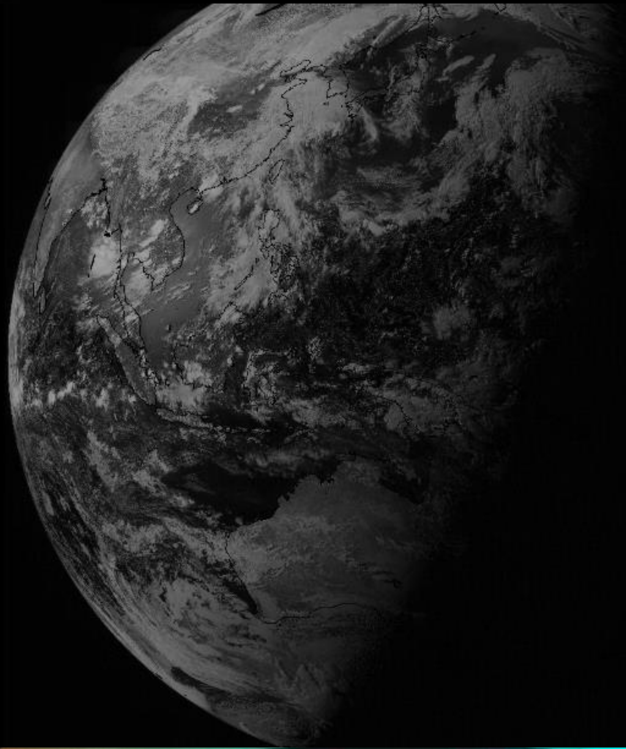
Far Infrared

Simultaneous images from the Japanese Himawari satellite at different wavelengths

0740 UCT 26 May 2019

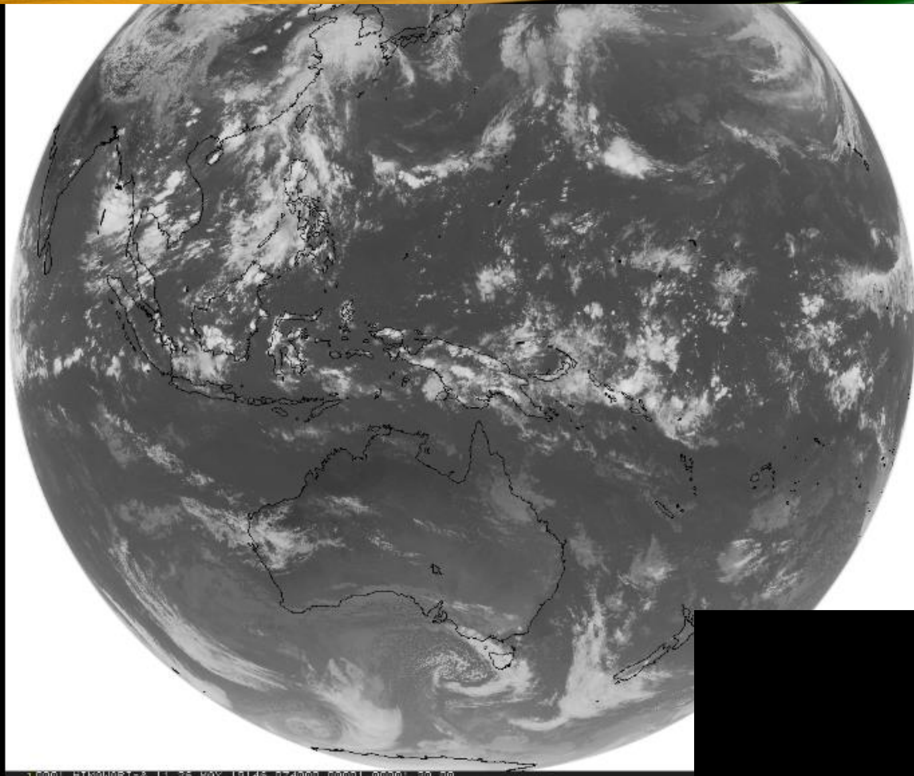


Visible
0.47 microns
(blue)



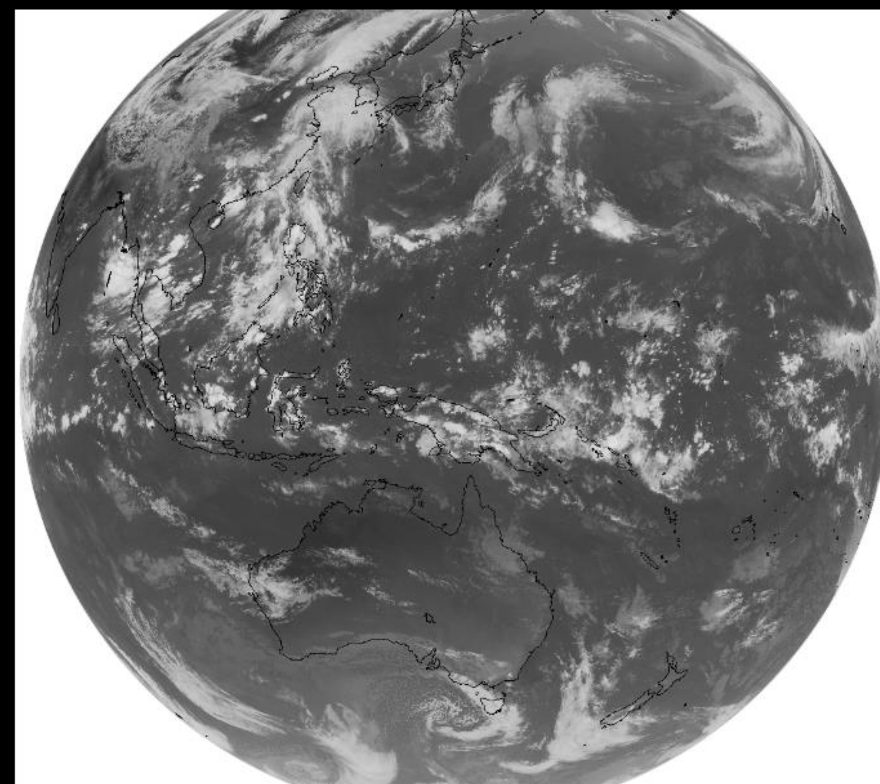
Near IR
2.6 microns

https://www.ssec.wisc.edu/data/geo/#/animation



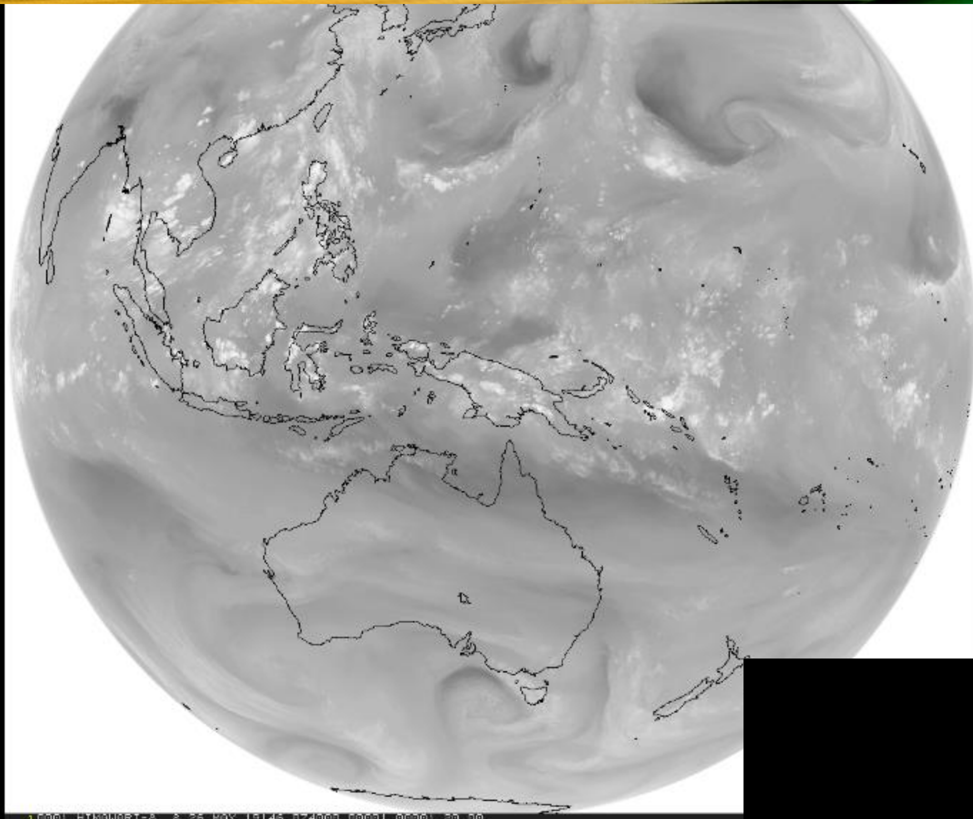
Long Wave
IR
8.6 microns

Long Wave
IR
11.2 microns



Simultaneous images from the Japanese Himawari satellite at different wavelengths

0740 UCT 26 May 2019

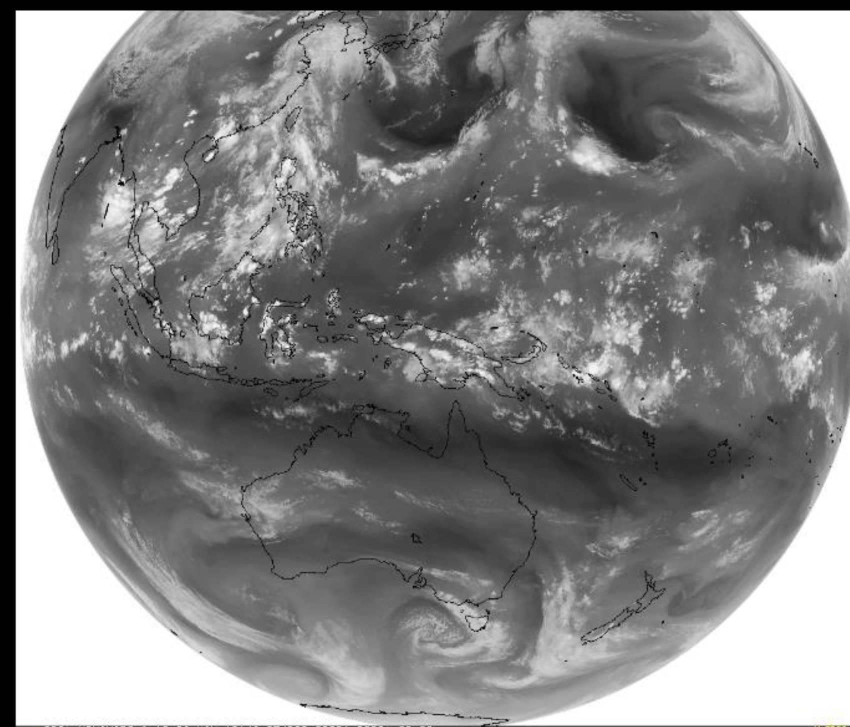


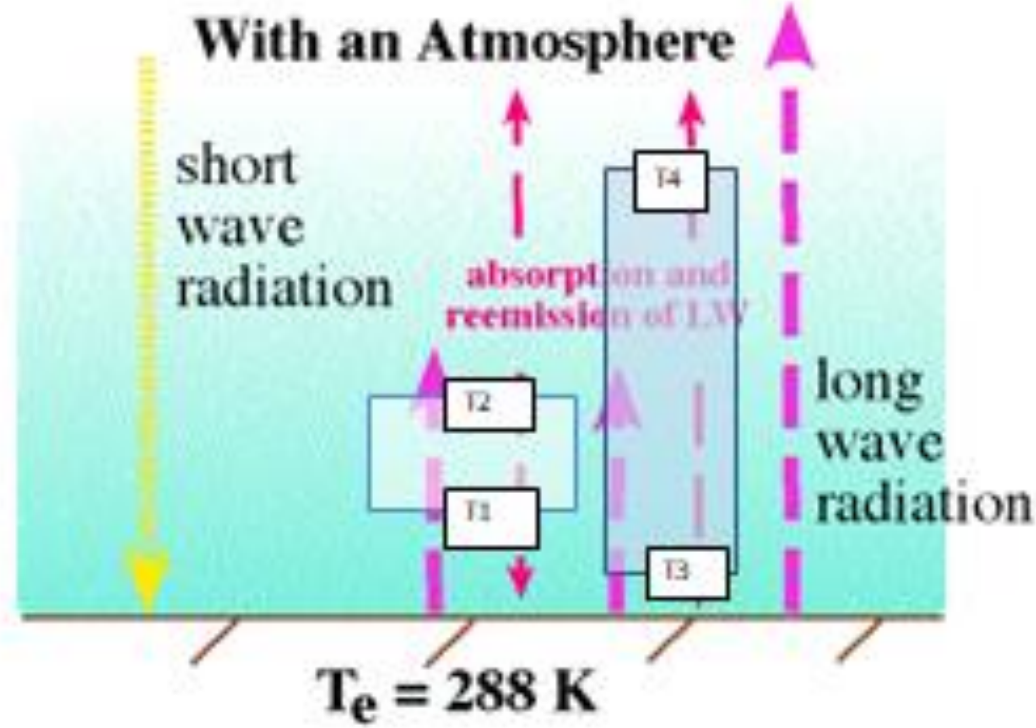
Water
vapour
(strong)
6.2
microns

Simultaneous images from the Japanese Himawari satellite at different wavelengths

0740 UCT 26 May 2019

Water
vapour
(weaker)
7.3
microns





Infrared energy may be absorbed by gases in the atmosphere and then re-transmitted out to space at its own temperature (which may be different from the temperature of the ground).

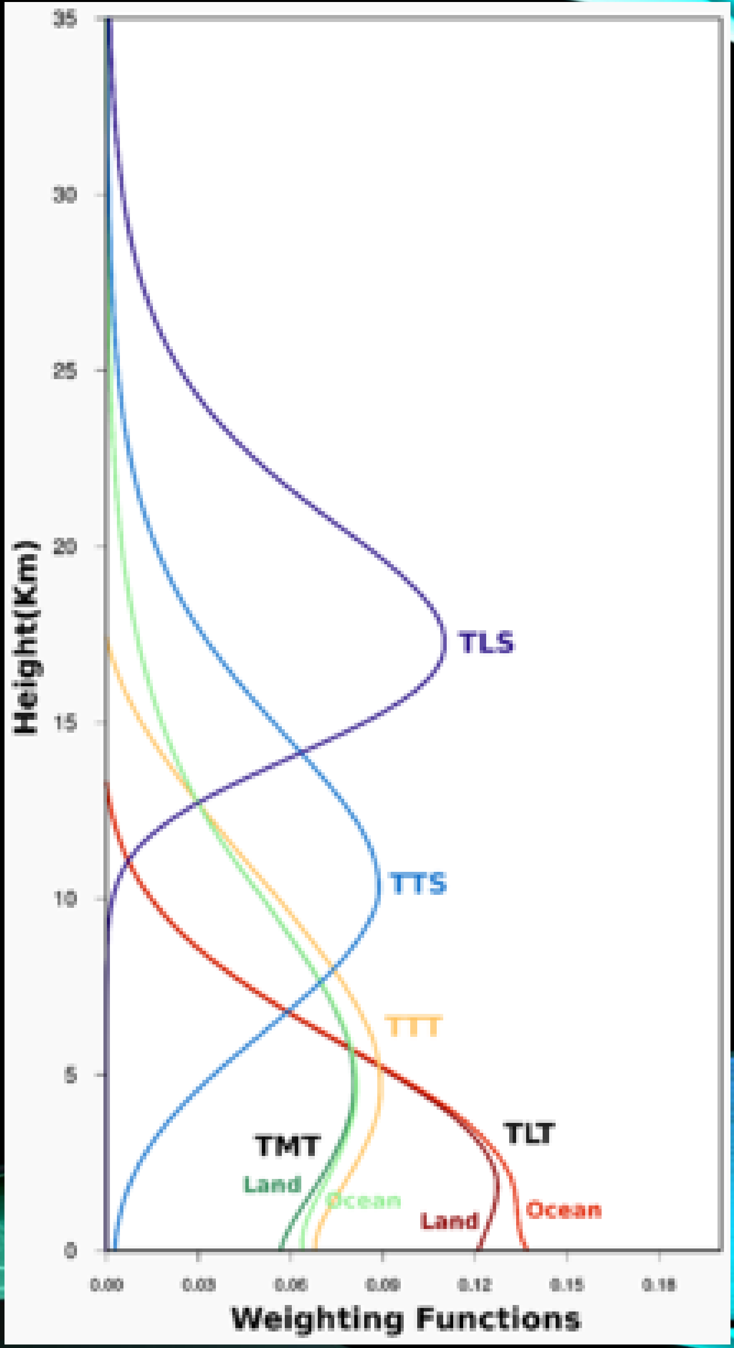
The principle of satellite temperature soundings is to take measurements at several wavelengths through an absorption band.

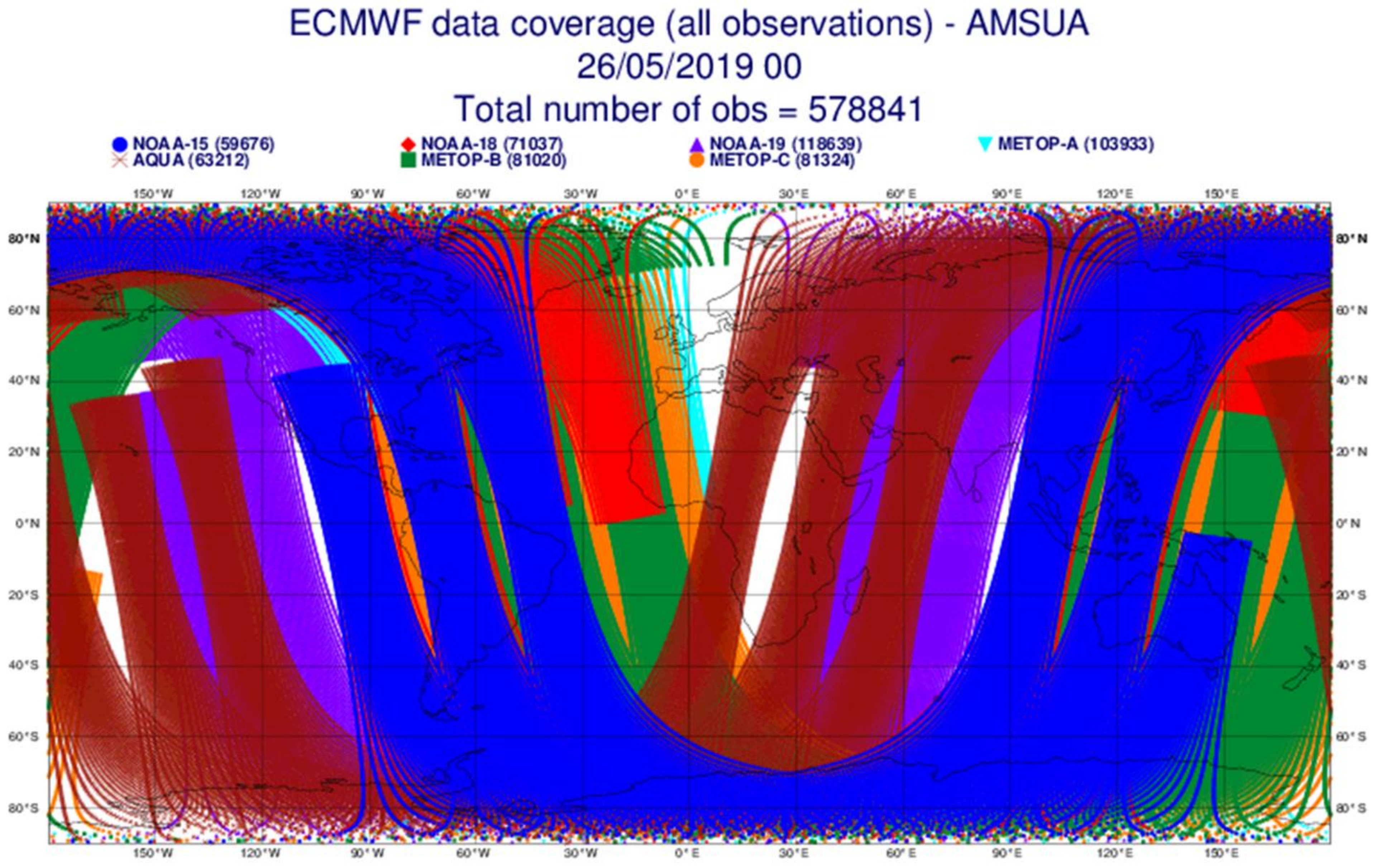
Where the absorption is strong, the radiation will come from the upper levels. Where the absorption is weak, the radiation will come from nearer the surface.

It needs a gas that is well mixed through the atmosphere and constant in composition.

Two good candidates are:
Carbon dioxide (Infrared 15 microns)
Oxygen (Microwave – around 55 GHz (5 mm))

Note: battle to keep the 55 GHz channels clear of human communications traffic.




ECMWF data coverage (all observations) - AMSUA
26/05/2019 00
Total number of obs = 578841
NOAA-15 (59676)
AQUA (63212)
NOAA-18 (71037)
METOP-B (81020)
NOAA-19 (118639)
METOP-C (81324)
METOP-A (103933)
150°W
120°W
90°W
60°W
30°W
0°E
30°E
60°E
90°E
120°E
150°E
80°N
60°N
40°N
20°N
0°N
20°S
40°S
60°S
80°S

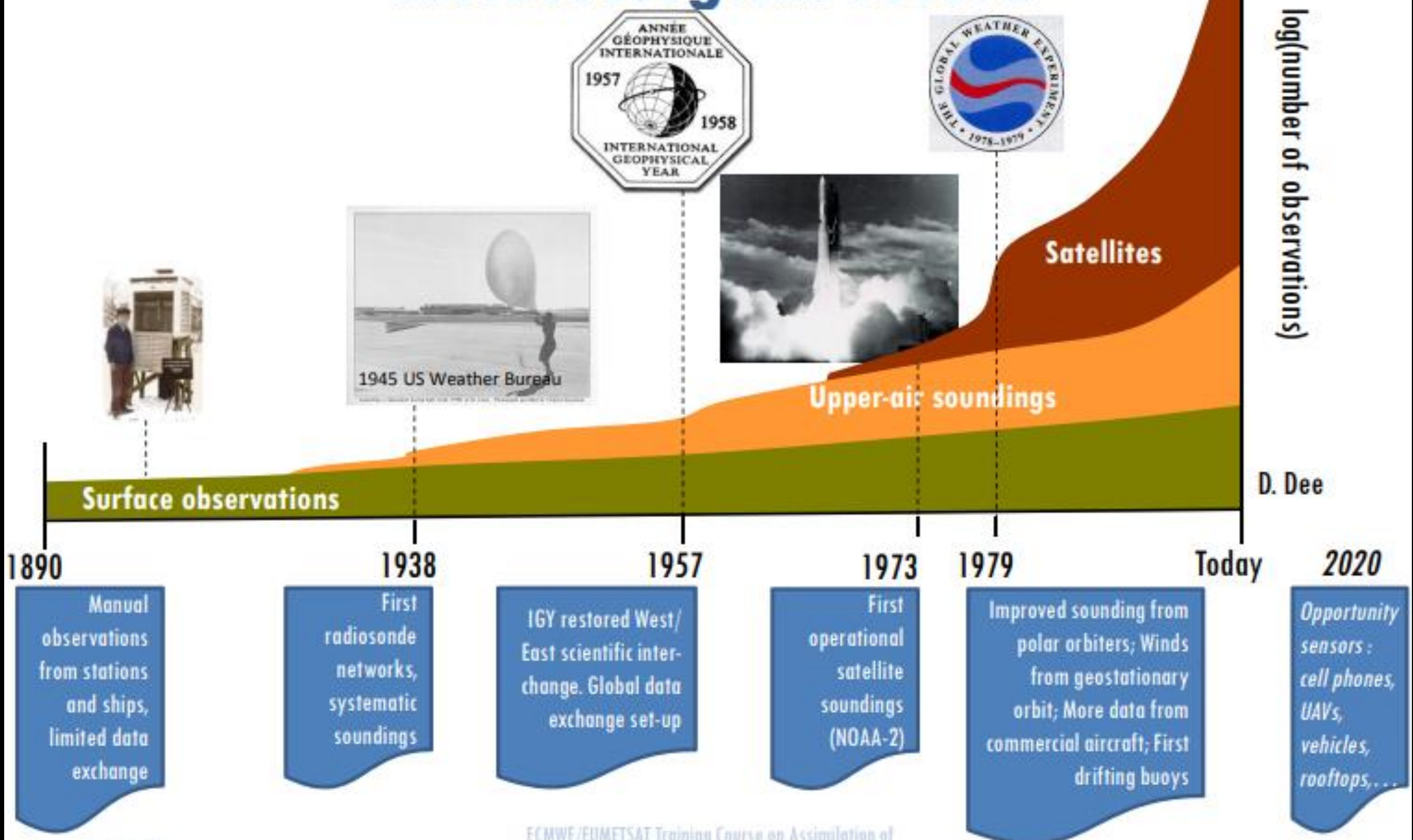
There are many types of satellite data used:

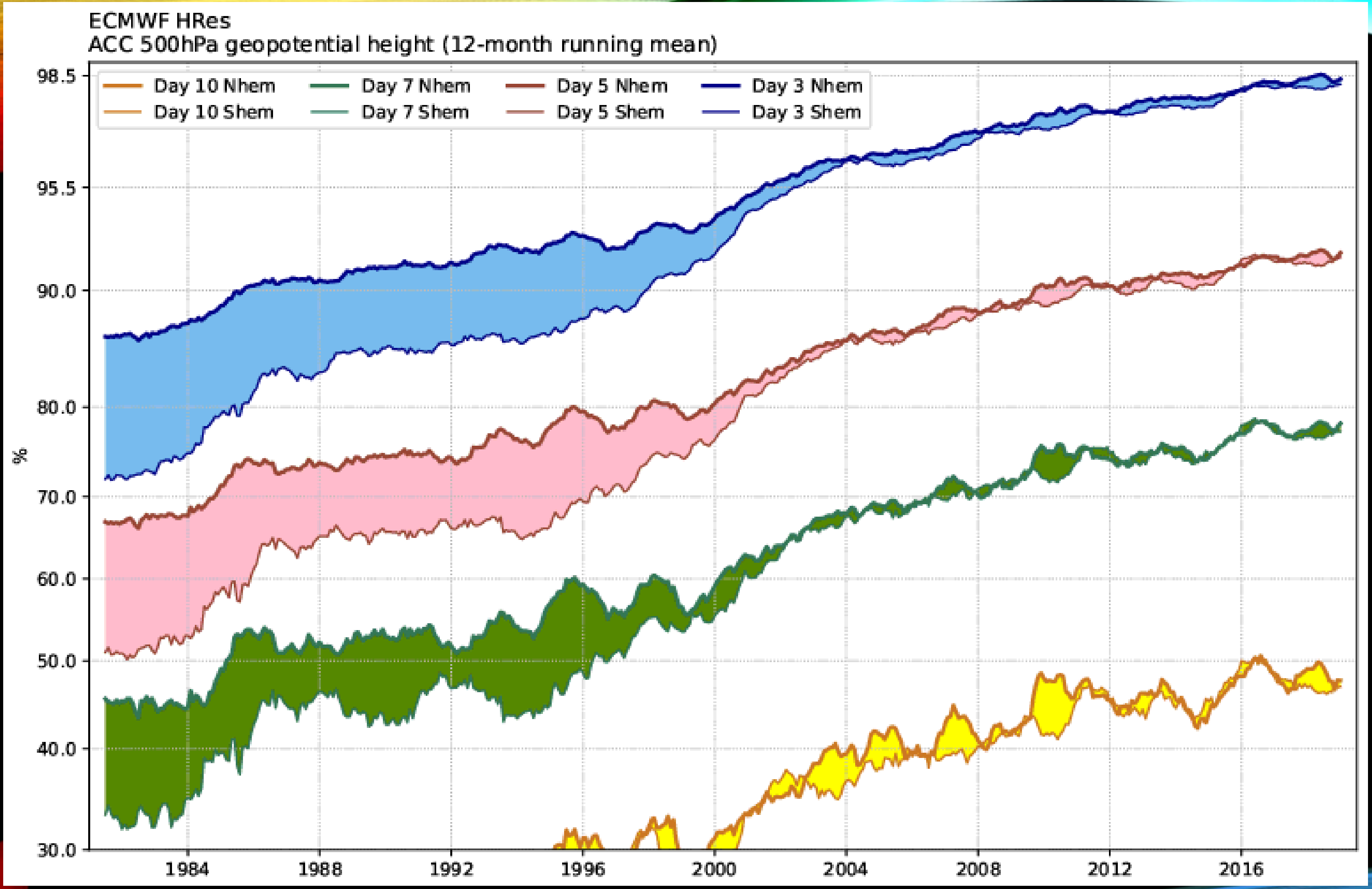
- Temperature sounding from radiation measurements
- Temperature sounding from occultation of GPS satellites
- Satellites with radar to measure ocean winds, height of waves and Sea level
- Satellites to measure soil moisture
- Measuring rainfall and water content
- Ozone

At ECMWF – 98 % of data received, and 95% of the data used come from satellites

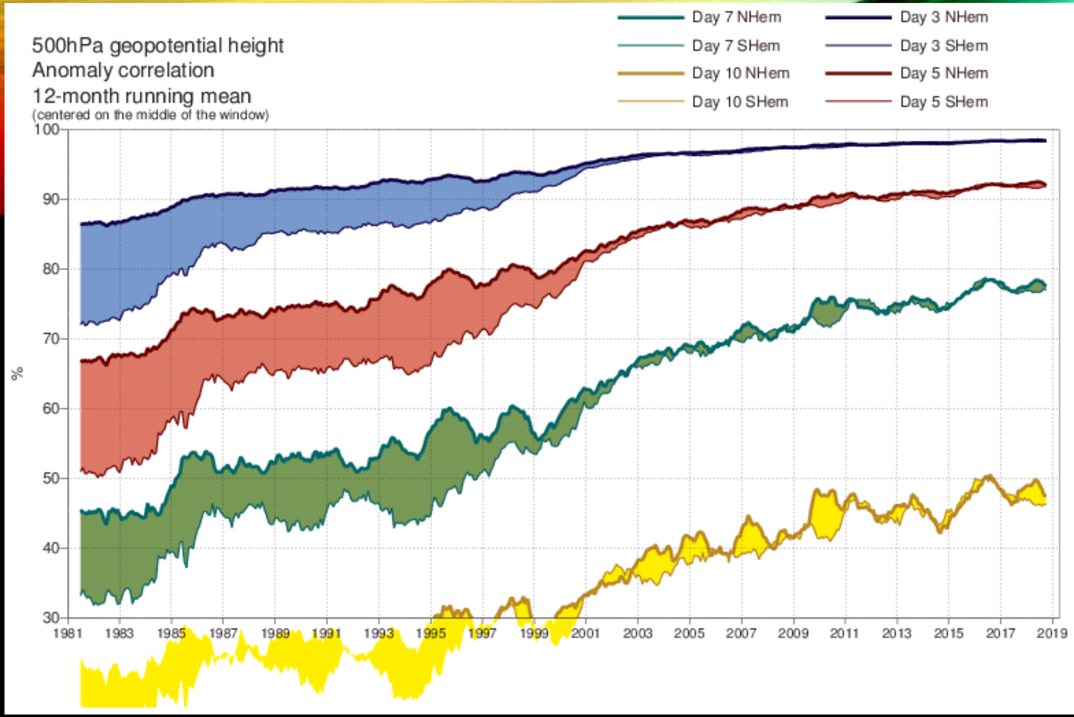
Satellite data have made a big difference to the skill of forecasts, and made the forecasting of the synoptic patterns in the southern hemisphere as accurate as in the north – a major achievement!

Placing satellite data in the global meteorological record





Time series showing the "skill" of the ECMWF computer predictions of the synoptic patterns of weather, at since 1981.
The number shows how well the forecast weather pattern correlates with the observed. So a higher number is good.



There are two main stories here and a question:

- The great improvement in weather prediction since the 1980s
- The closing of the gap between the skill of forecasts in the northern and southern hemispheres (mainly due to satellite data)
- Question: why does the forecast skill deteriorate at longer range?