Understanding weather and the weather forecast

Week 30

Forecasting the Weather

Terry Hart

Because:

- We live on a spherical planet where the incoming energy from the sun is greater in the tropics than in the polar areas
- We have an atmosphere and ocean which try to even out the energy imbalance
- We live on a rotating planet that complicates the work of the atmosphere and ocean by deflecting winds (and currents) that develop. (Coriolis Force)
- Land and ocean, mountain ranges and different types of surface add their own effects.

Forecasting the Weather

A bit like a consultation with your doctor:

- First step is diagnosis
- Then prognosis and treatment.

In weather forecasting the first step is to analyse the weather now, and then to make a forecast. The “**weather map**” is one of the results from the analysis stage.

The method of making a forecast will depend on factors such as:

- What element are you interested in?
- How far ahead do you need a forecast?

	T	rain	cloud	wind	RH	Pheno mena	How far out?
You							
Sailor							
Farmer							
Firefighter							
Aircraft Pilot							

Imagine we are just interested in the general weather for tomorrow? What techniques could we use?

Persistence

Assume tomorrow's weather will be the same as today's

Climatology

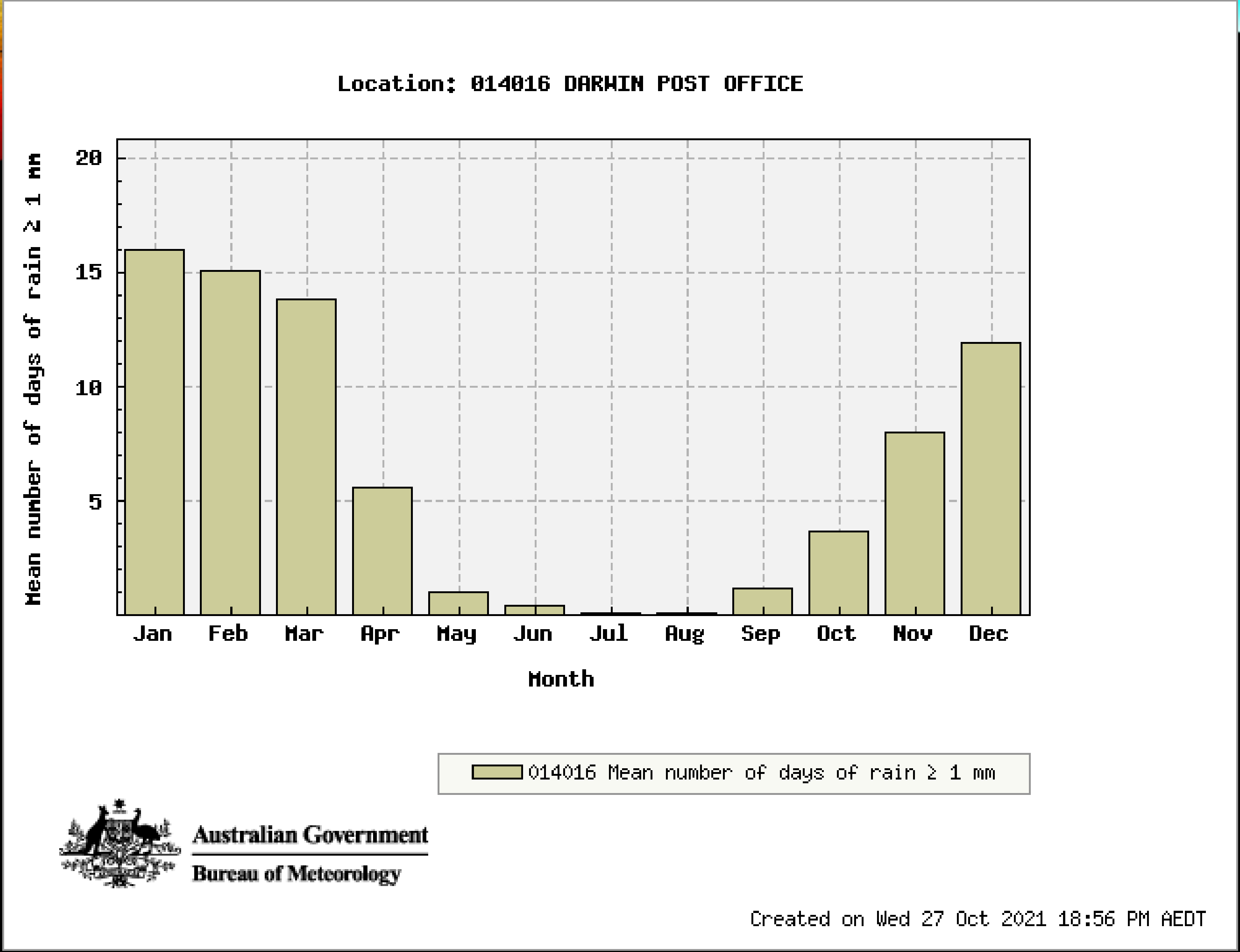
Assume that the weather will be typical for the time of year for the location you are interested in

This could include the daily trend and regular features such as a sea breeze.

Rules of thumb or local knowledge

e.g. . rings around the moon are a sign of rain to come
. red sky at night, shepherd's delight, …
. it's always 40 degrees on Christmas Day
. the sea breeze will come in when the cloud clears.

Figure 6.2 Daily mean temperatures during March in Edmonton, Singapore, New Delhi and Canberra during 2000, 2001, 2002 and 2005.



Darwin Post Office – average number of days with rain > 1mm 1869 to 1962

Extrapolation

. Watching the upstream weather

e.g. Melbourne will have tomorrow what Adelaide had today.

. A **useful technique for short-term forecasts based on radar or satellite images.**

Creating a forecast weather chart

Move the weather features on the synoptic chart at the rate at which they have been moving

Look at the pressure changes and project the pressure changes and apply them to the weather chart

Analogue

Find a past weather chart similar to today's and use the weather that happened on that occasion

Looking for some underlying cause
e.g. sunspots, sea surface temperature patterns

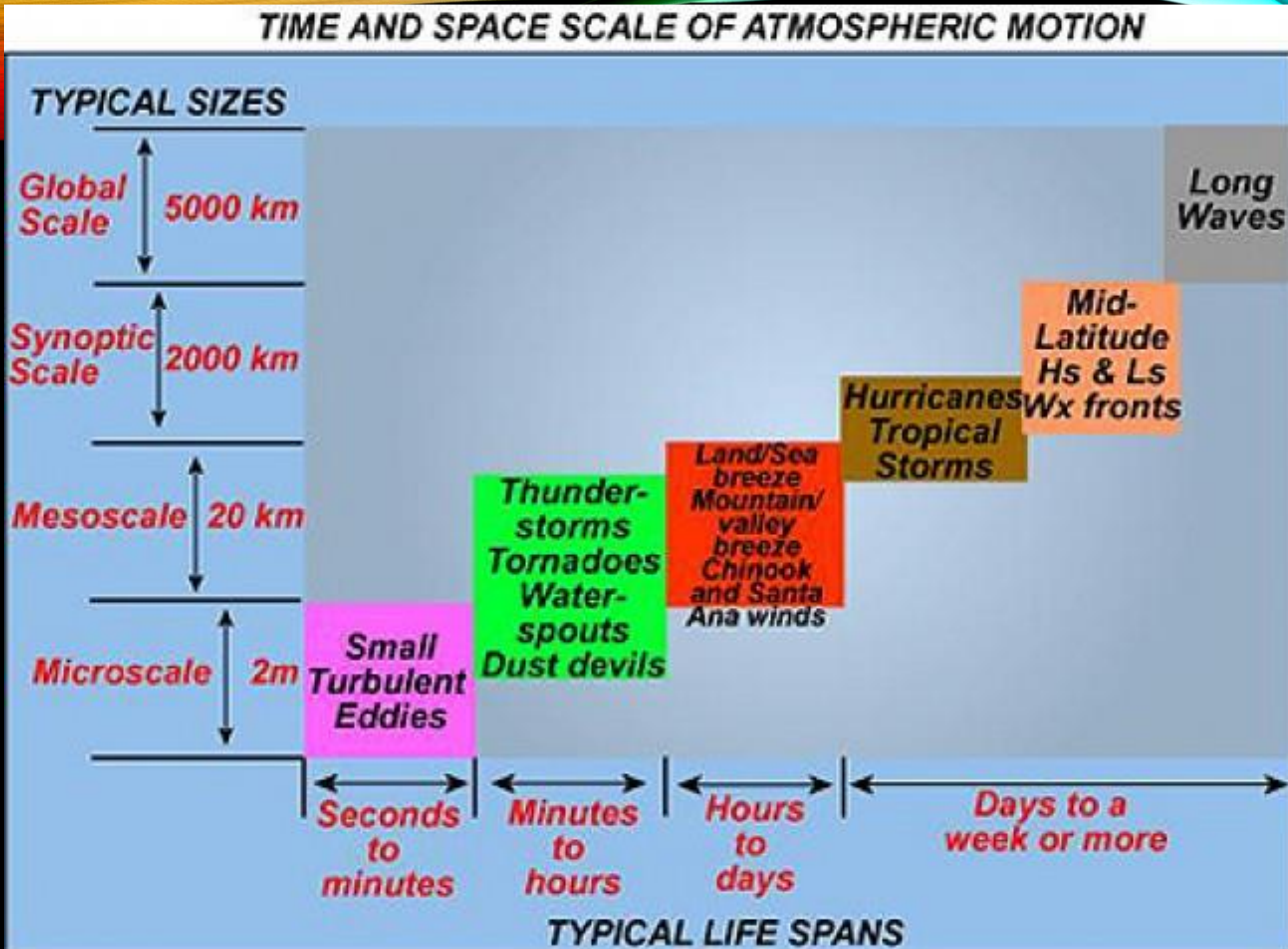
Statistical techniques
Seasonal forecasts are mainly statistical – correlations sea surface temperature patterns.

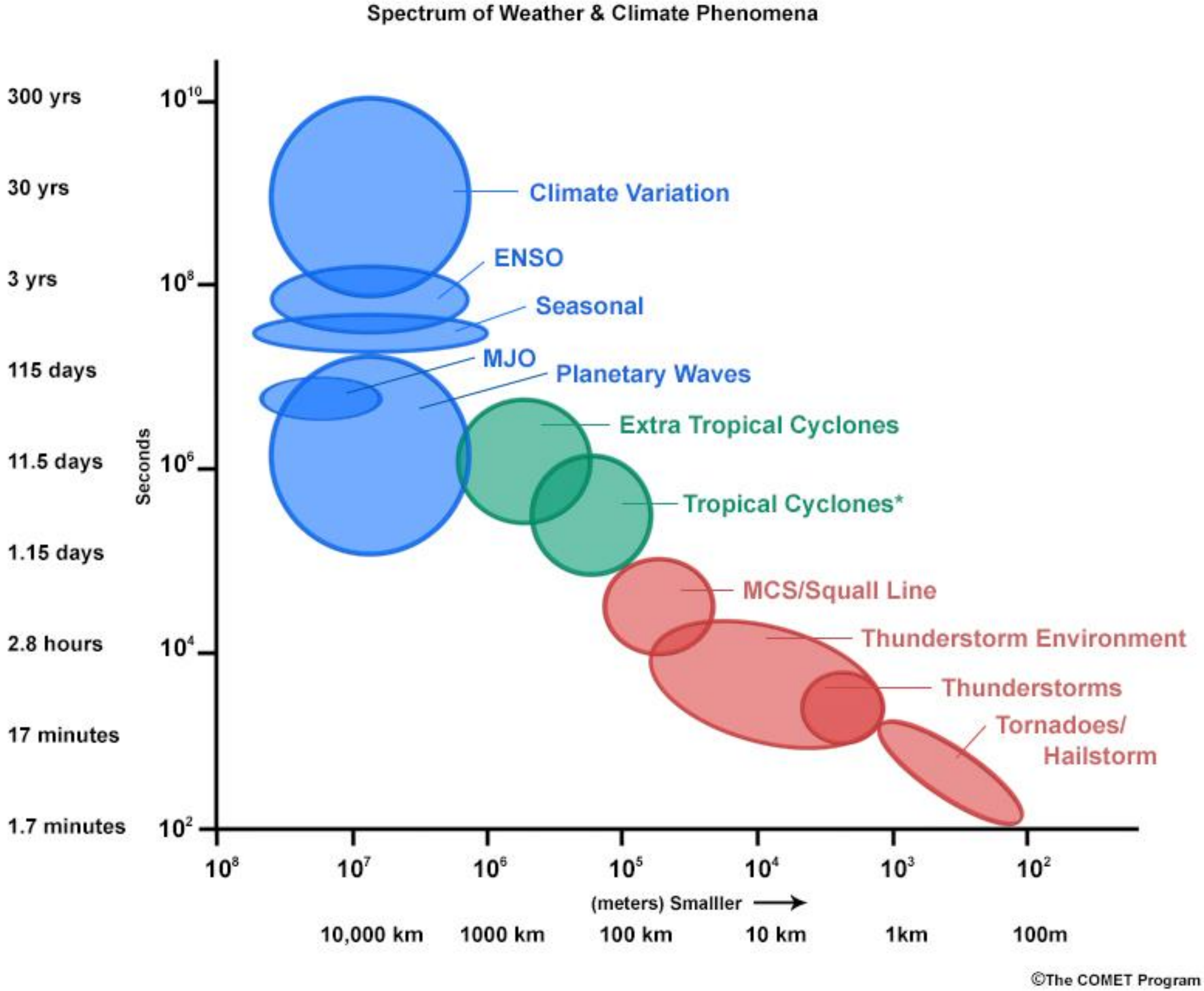
Numerical (Computer) Weather Prediction

Using a computer to analyse the current weather and use equations to predict the weather ahead.

No one method is the best all the time.

All techniques have their appropriate time and place, and method of use.

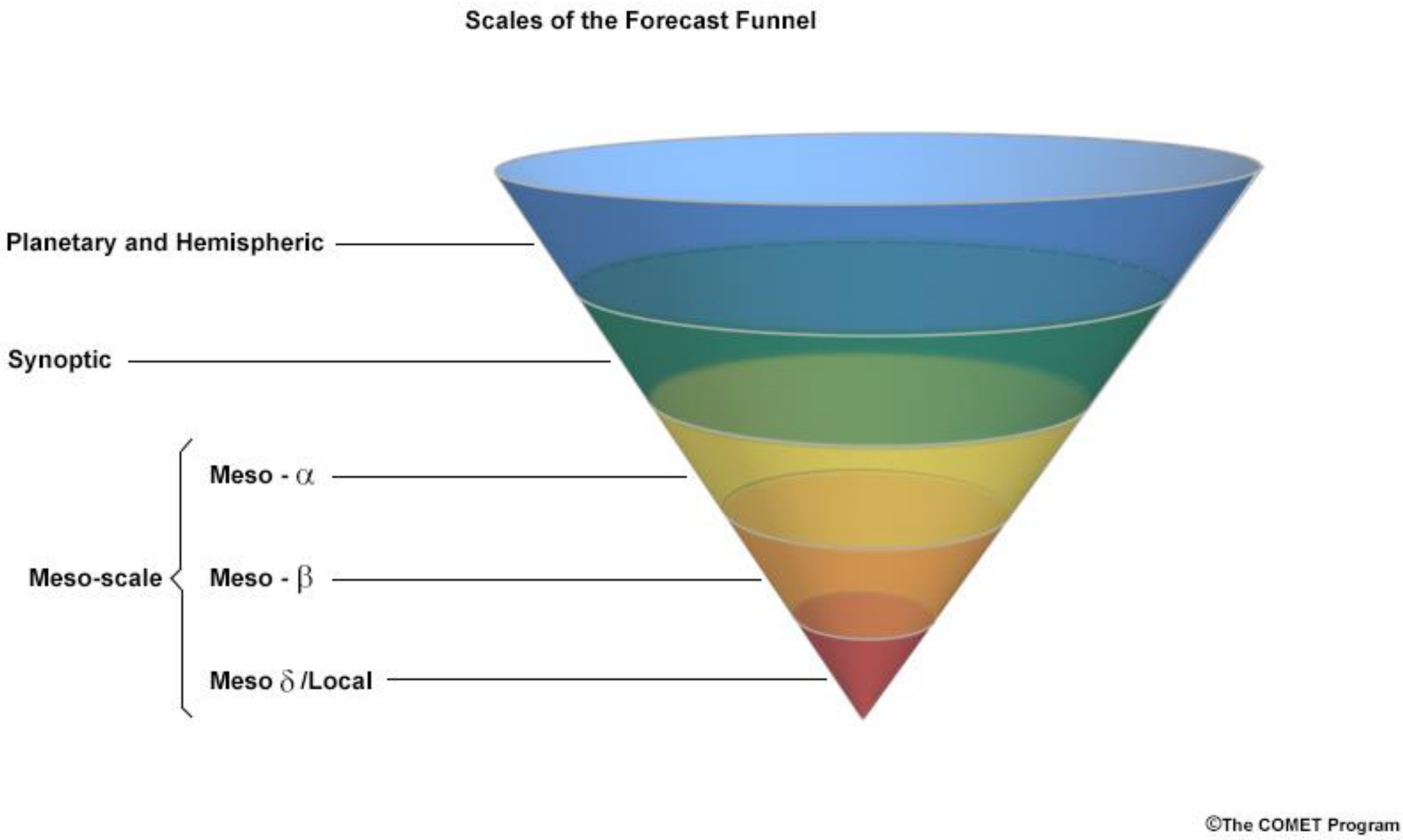

TIME AND SPACE SCALE OF ATMOSPHERIC MOTION
TYPICAL SIZES
Global Scale
5000 km
Synoptic Scale
2000 km
Mesoscale
20 km
Microscale
2m
Small Turbulent Eddies
Thunder-storms Tornadoes Water-spouts Dust devils
Land/Sea breeze Mountain/valley breeze Chinook and Santa Ana winds
Hurricanes Tropical Storms
Mid-Latitude Hs & Ls Wx fronts
Long Waves
Seconds to minutes
Minutes to hours
Hours to days
Days to a week or more
TYPICAL LIFE SPANS

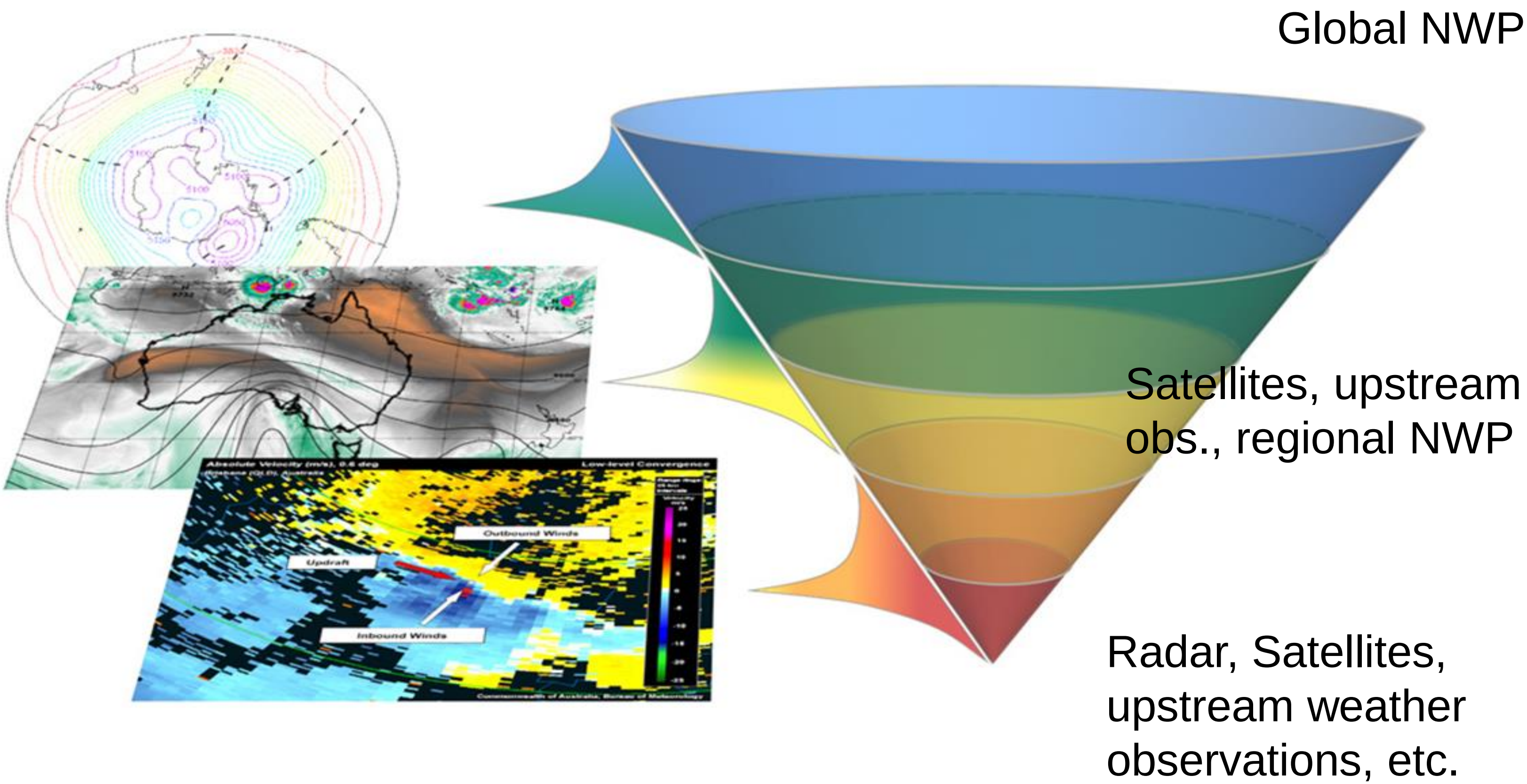


Spectrum of Weather & Climate Phenomena
300 yrs
30 yrs
3 yrs
115 days
11.5 days
1.15 days
2.8 hours
17 minutes
1.7 minutes
Seconds
10^{10}
10^{8}
10^{6}
10^{4}
10^{2}
Climate Variation
ENSO
Seasonal
MJO
Planetary Waves
Extra Tropical Cyclones
Tropical Cyclones*
MCS/Squall Line
Thunderstorm Environment
Thunderstorms
Tornadoes/
Hailstorm
10^{8} 10^{7} 10^{6} 10^{5} 10^{4} 10^{3} 10^{2}
(meters) Smalller
10,000 km
1000 km
100 km
10 km
1km
100m
©The COMET Program

Forecast Funnel

Understand the broad scale pattern then work toward the smaller scales.



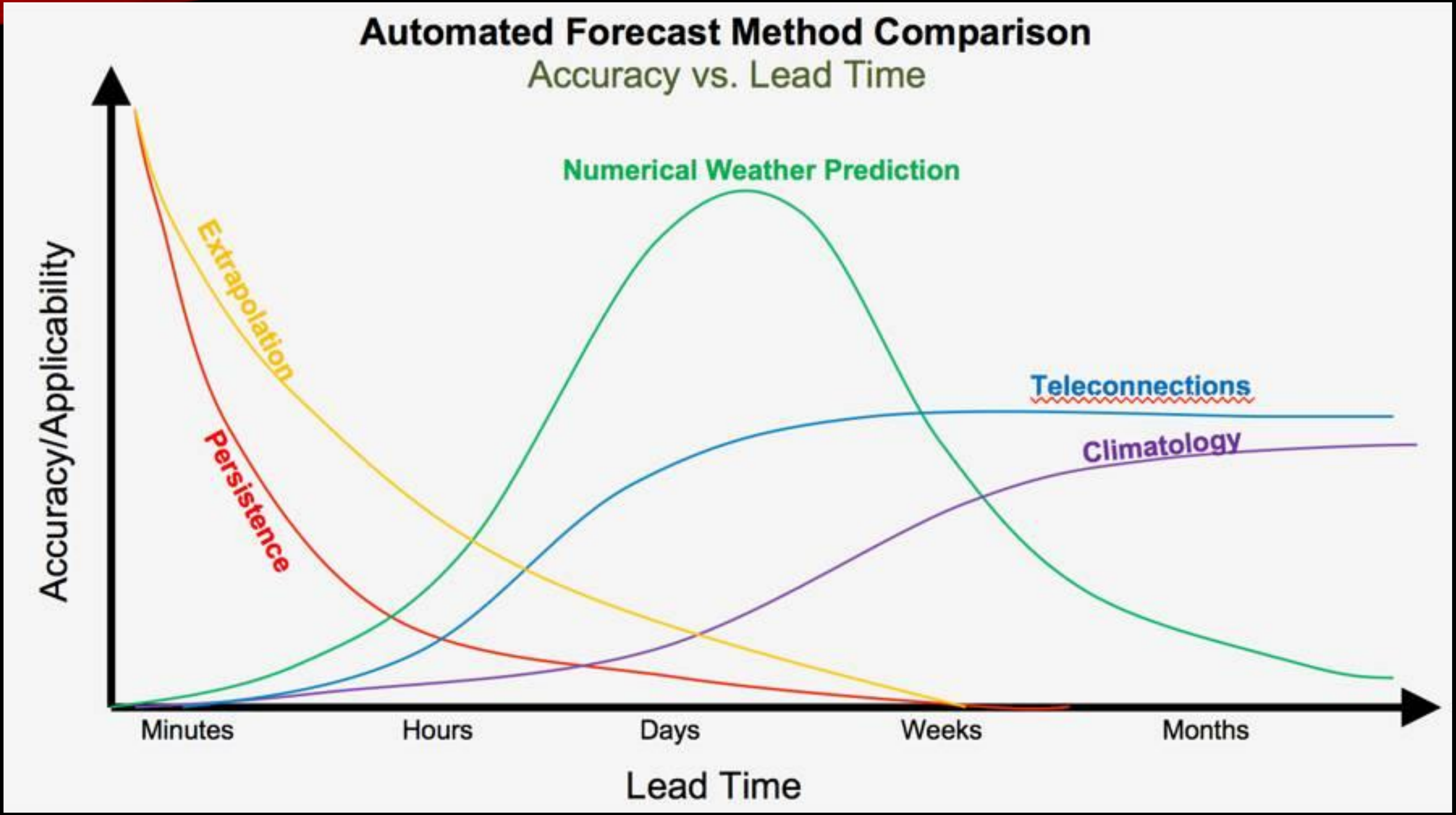


Different forecasting techniques are more suitable at different scales

Bureau of Meteorology (Australia)/The COMET Program

Radar examples

MelbRadar_ColdOutbreak_31May2022

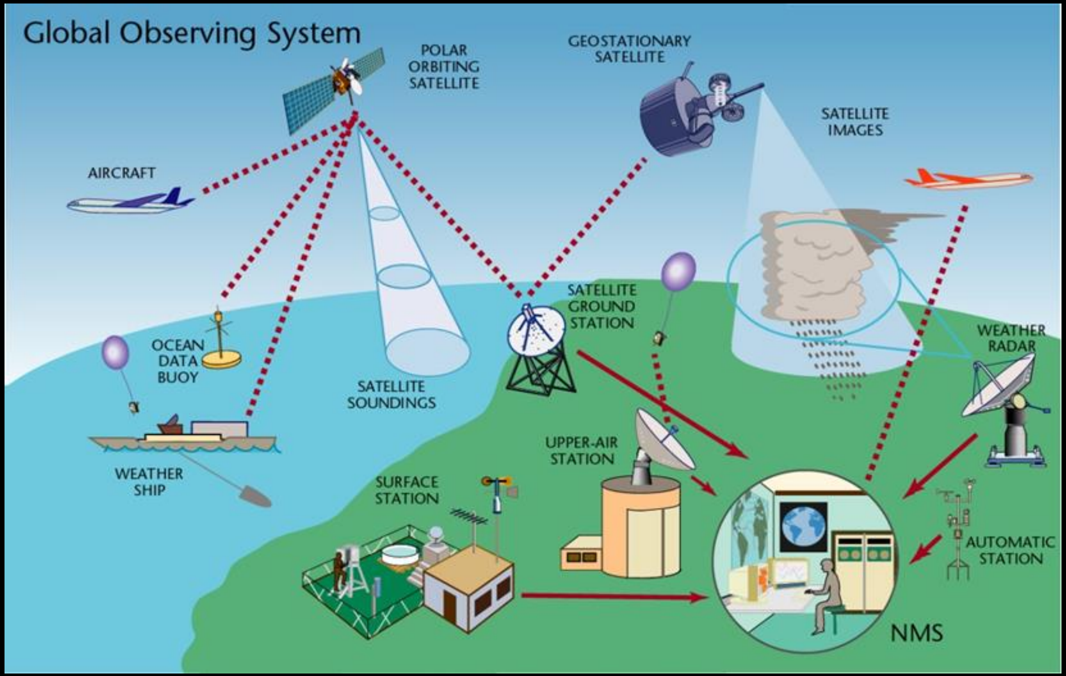

Automated Forecast Method Comparison
Accuracy vs. Lead Time
Numerical Weather Prediction
Extrapolation
Persistence
Teleconnections
Climatology
Accuracy/Applicability
Minutes
Hours
Days
Weeks
Months
Lead Time

Computer Weather Prediction
(or Numerical Weather Prediction)

- We have equations that tell how things will change in the atmosphere (e.g. Vilhelm Bjerknes), but we need to know what the atmosphere looks like to start with.

- Importance of weather observations and analysis

- Like seeing a doctor – analysis before prognosis and treatment



Climate models are basically the same apart from more details on the ocean, etc. They are long term averages and so do not rely so much on the starting point.

Equations of the atmosphere

1. How the wind will change as a result of all the forces acting on it such as:
- Pressure differences
- Coriolis force
- Gravity
- Friction. *(Basically Newton's Second Law on a sphere)*

2. How the local temperature will change due to effects such as:
- Movement of nearby air with different temperature
- Cooling of air by expansion or compression
- Effects of incoming sunlight or outgoing infrared
- Condensation/evaporation, conduction

3. How temperature, pressure and density are connected
(Ideal Gas Law)

4. Amount of air stays constant ("continuity equation" or conservation of mass)

5. Water vapour budget - rainfall, evaporation and changes in water vapour amount.

PE for ECMWF model

East-west wind

$$\frac{\partial U}{\partial t} + \frac{1}{a\cos^2\theta}\left\{U\frac{\partial U}{\partial \lambda} + V\cos\theta\frac{\partial U}{\partial \theta}\right\} + \dot{\eta}\frac{\partial U}{\partial \eta}$$

$$(-fV) + \frac{1}{a}\left\{\frac{\partial \phi}{\partial \lambda} + R_{dry}T_v\frac{\partial}{\partial \lambda}(\ln p)\right\} = \underline{P_U + K_U}$$

North-south wind

$$\frac{\partial V}{\partial t} + \frac{1}{a\cos^2\theta}\left\{U\frac{\partial V}{\partial \lambda} + V\cos\theta\frac{\partial V}{\partial \theta} + \sin\theta(U^2+V^2)\right\} + \dot{\eta}\frac{\partial V}{\partial \eta}$$

$$+ fU + \frac{\cos\theta}{a}\left\{\frac{\partial \phi}{\partial \theta} + R_{dry}T_v\frac{\partial}{\partial \theta}(\ln p)\right\} = \underline{P_V + K_V}$$

Temperature

$$\frac{\partial T}{\partial t} + \frac{1}{a\cos^2\theta}\left\{U\frac{\partial T}{\partial \lambda} + V\cos\theta\frac{\partial T}{\partial \theta}\right\} + \dot{\eta}\frac{\partial T}{\partial \eta} - \frac{\kappa T_v \omega}{(1+(\delta-1)q)p} = \underline{P_T + K_T}$$

Humidity

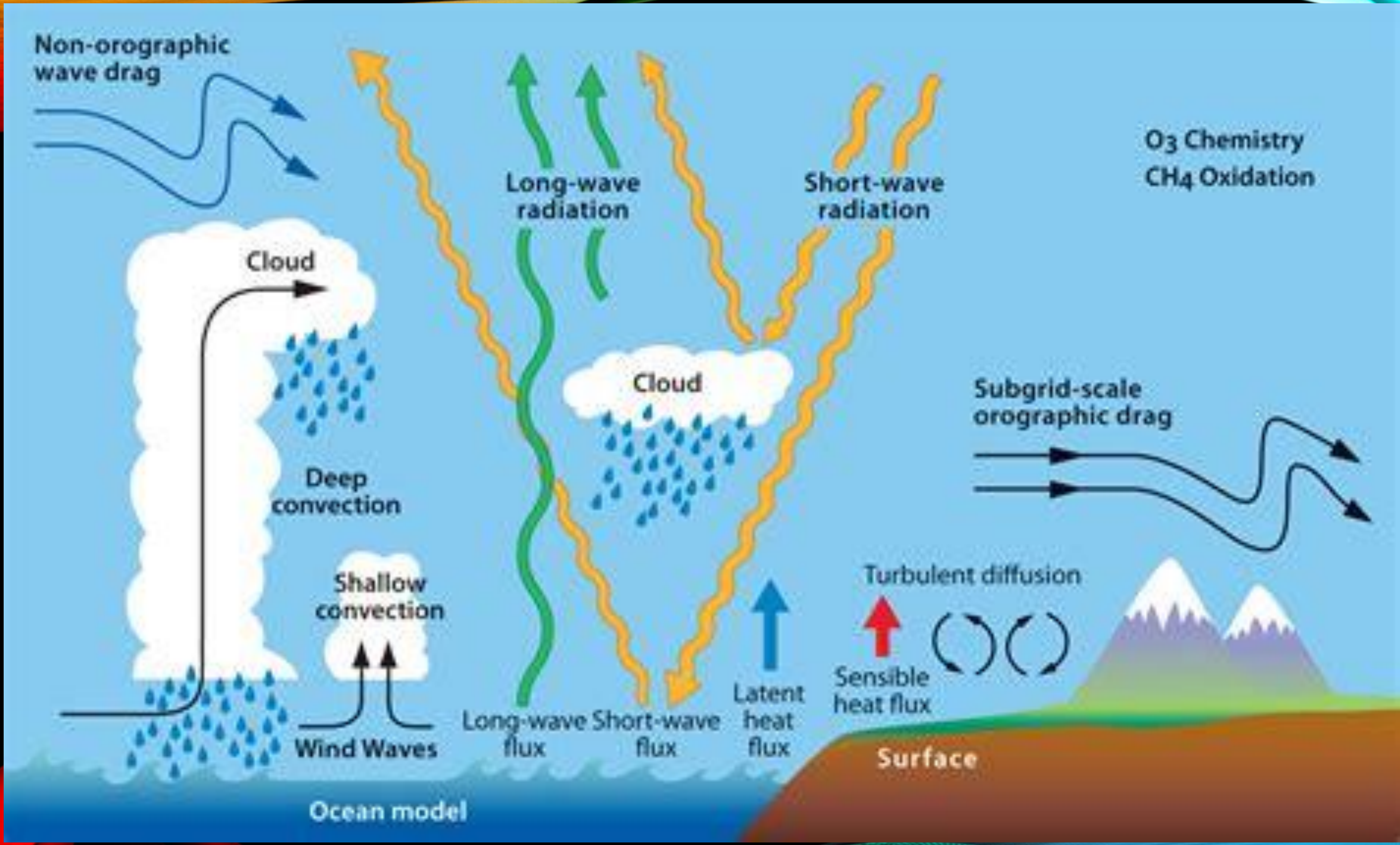
$$\frac{\partial q}{\partial t} = \frac{1}{a\cos^2\theta}\left\{U\frac{\partial q}{\partial \lambda} + V\cos\theta\frac{\partial q}{\partial \theta}\right\} = \dot{\eta}\frac{\partial q}{\partial \eta} = \underline{P_q + K_q}$$

Continuity of mass

$$\frac{\partial}{\partial t}\left(\frac{\partial p}{\partial \eta}\right) + \nabla\cdot\left(\mathbf{v}_H\frac{\partial p}{\partial \eta}\right) + \frac{\partial}{\partial \eta}\left(\dot{\eta}\frac{\partial p}{\partial \eta}\right) = 0$$

Surface pressure

$$\frac{\partial p_{surf}}{\partial t} = -\int_0^1 \nabla\cdot\left(\mathbf{v}_H\frac{\partial p}{\partial \eta}\right)d\eta$$



Typical atmospheric processes modelled in a computer weather prediction model

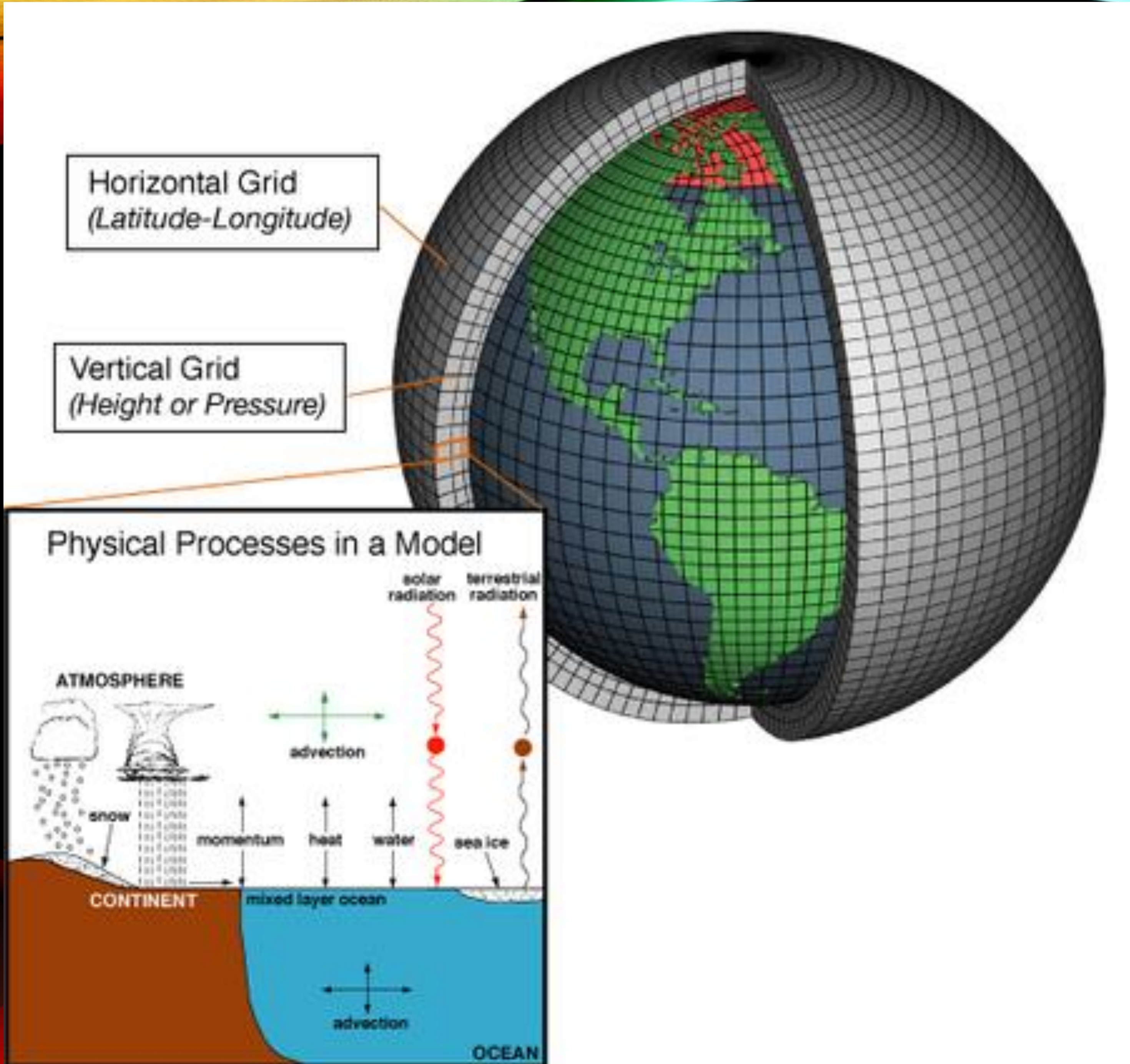
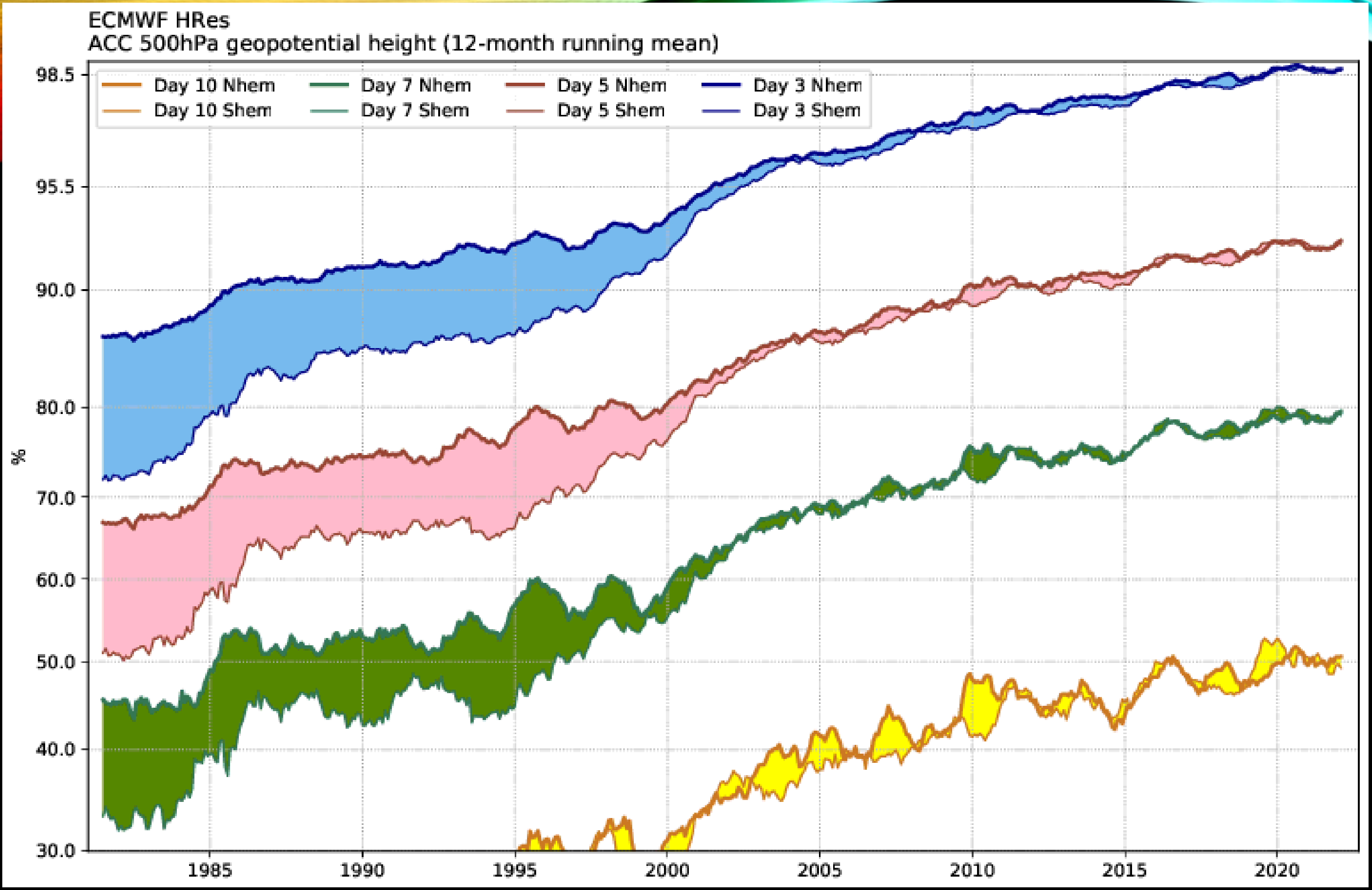

Horizontal Grid
(Latitude-Longitude)
Vertical Grid
(Height or Pressure)
Physical Processes in a Model
solar radiation
terrestrial radiation
ATMOSPHERE
advection
snow
momentum
heat
water
sea ice
CONTINENT
mixed layer ocean
advection
OCEAN

Figure 1. A schematic showing grid points, both horizontal and vertical, at which calculations are made in a numerical prediction model of the atmosphere. (Source: Bureau of Meteorology)

To make the mesh of grid points finer, needs more computing power

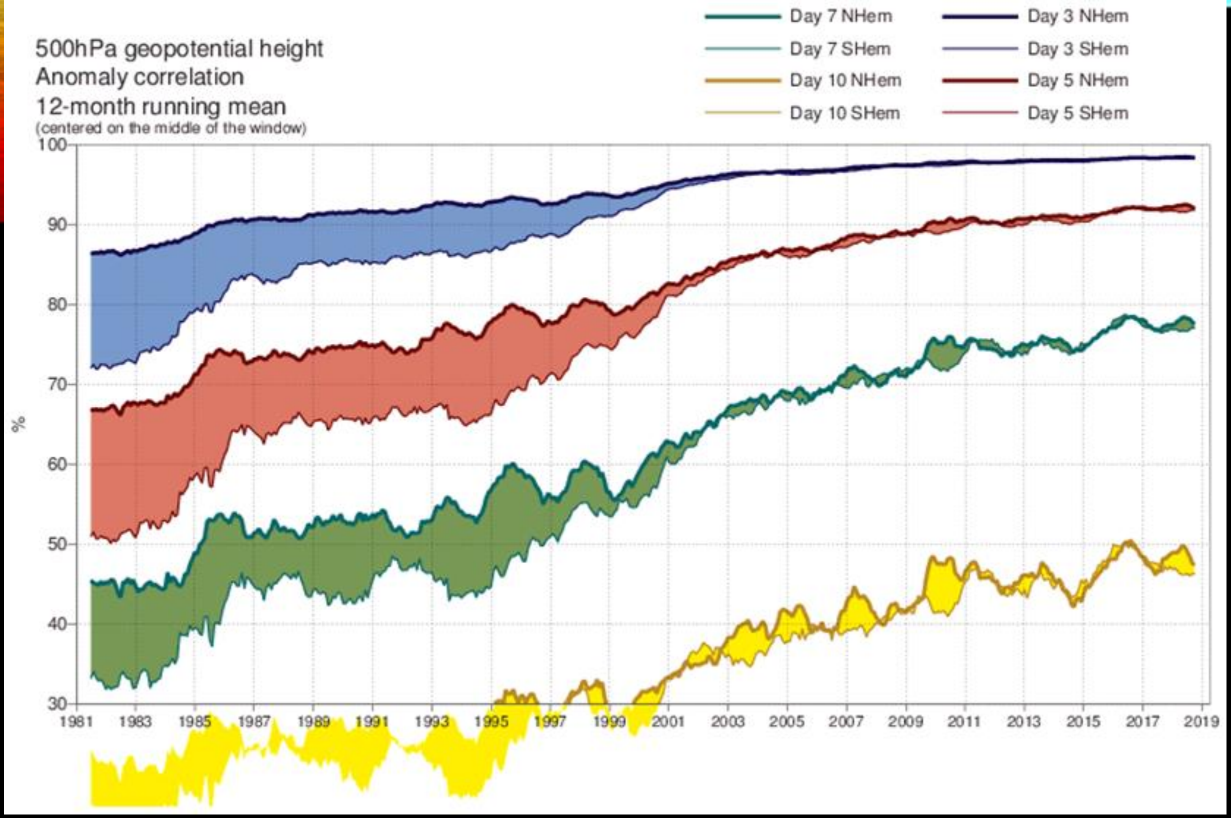
Figure 5. The Bureau of Meteorology's current Cray supercomputer. (Source: Tim Pugh, Bureau of Meteorology)

Some of the biggest supercomputers in the world are operated by meteorological agencies.



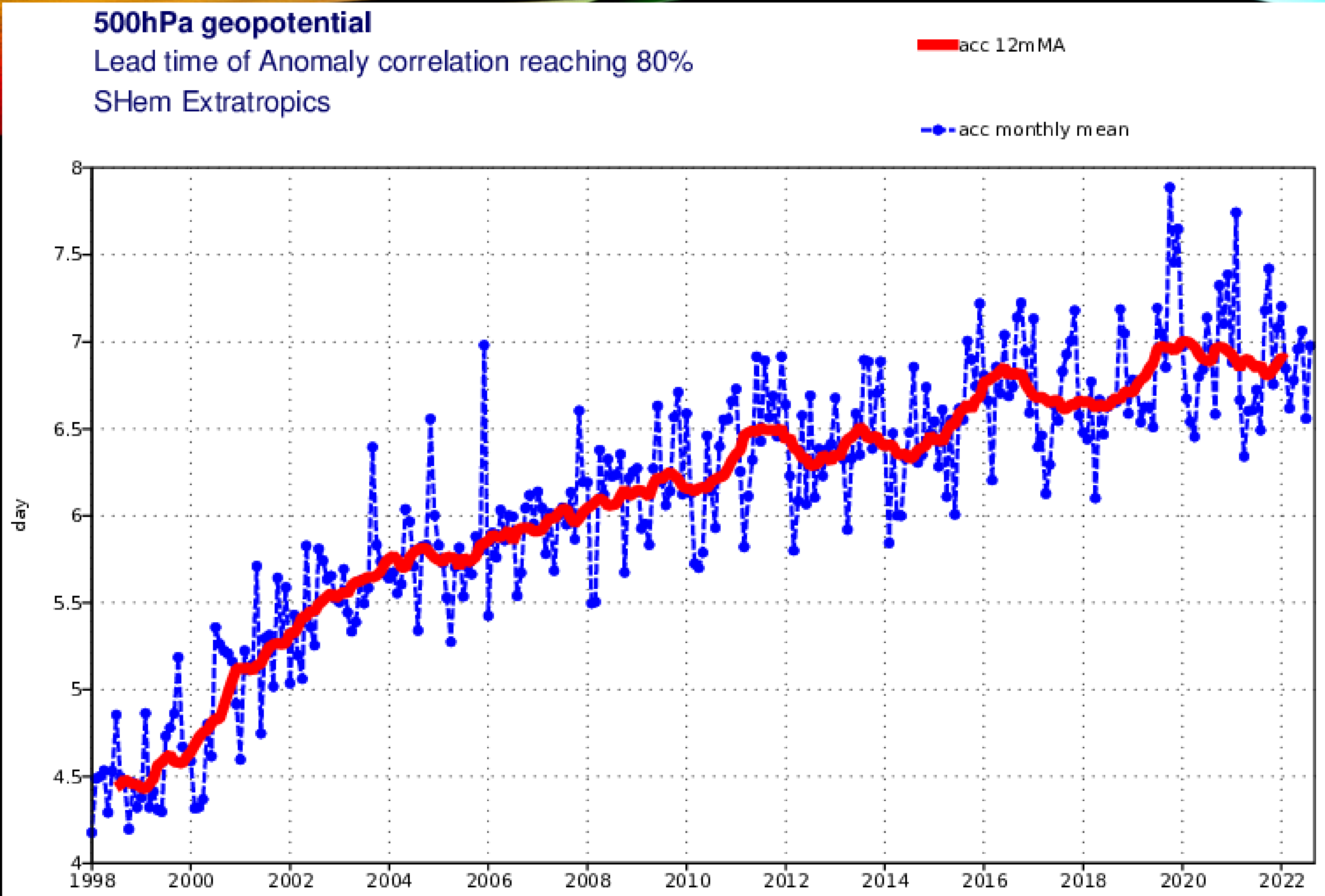
Time series showing the “skill” of the ECMWF computer predictions of the synoptic patterns of weather, at since 1981.

The number shows how well the forecast weather pattern correlates with the observed. So a higher number is good. https://charts.ecmwf.int/products/plwww_m_hr_ccaf_adrian_ts

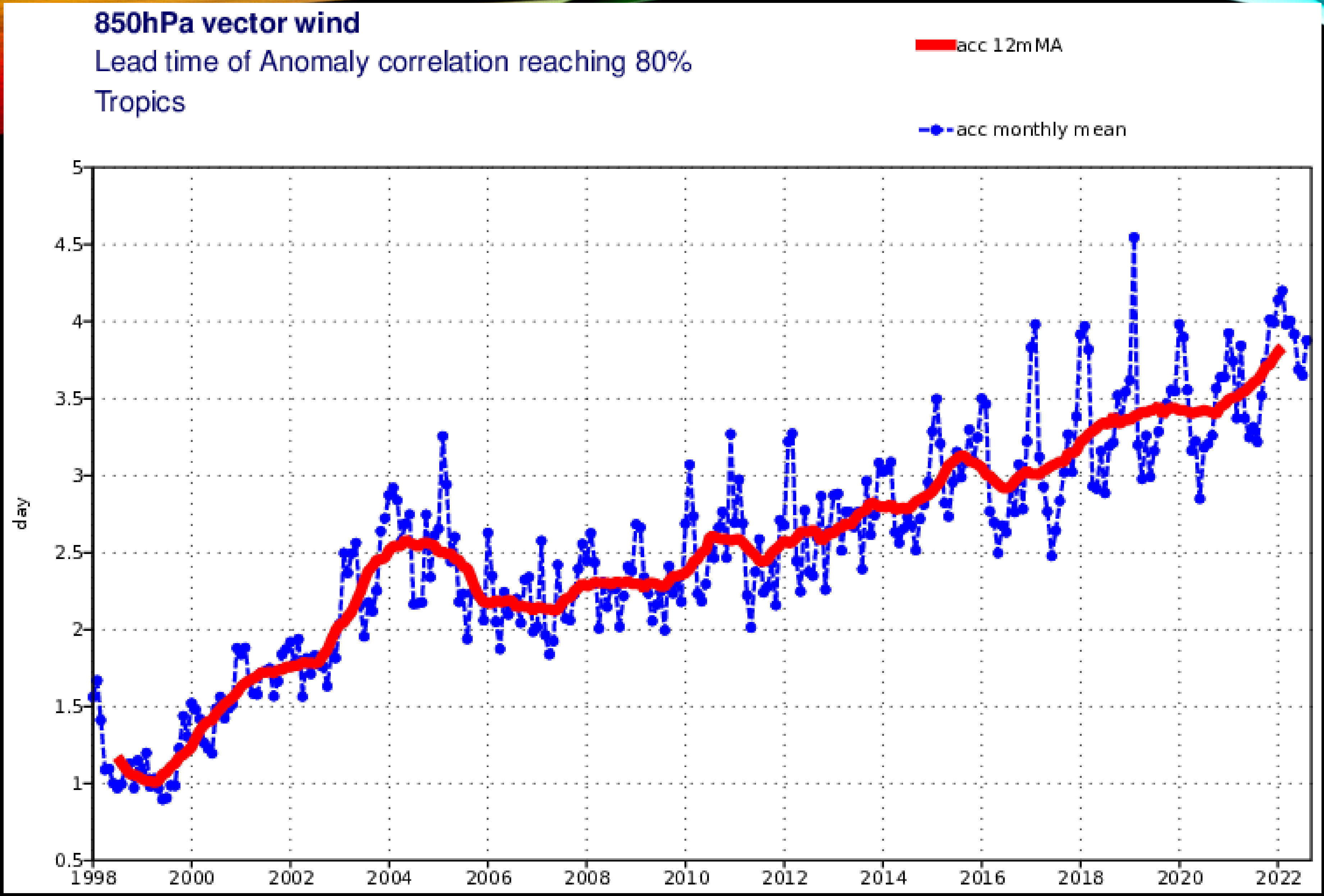


Every picture tells a story.

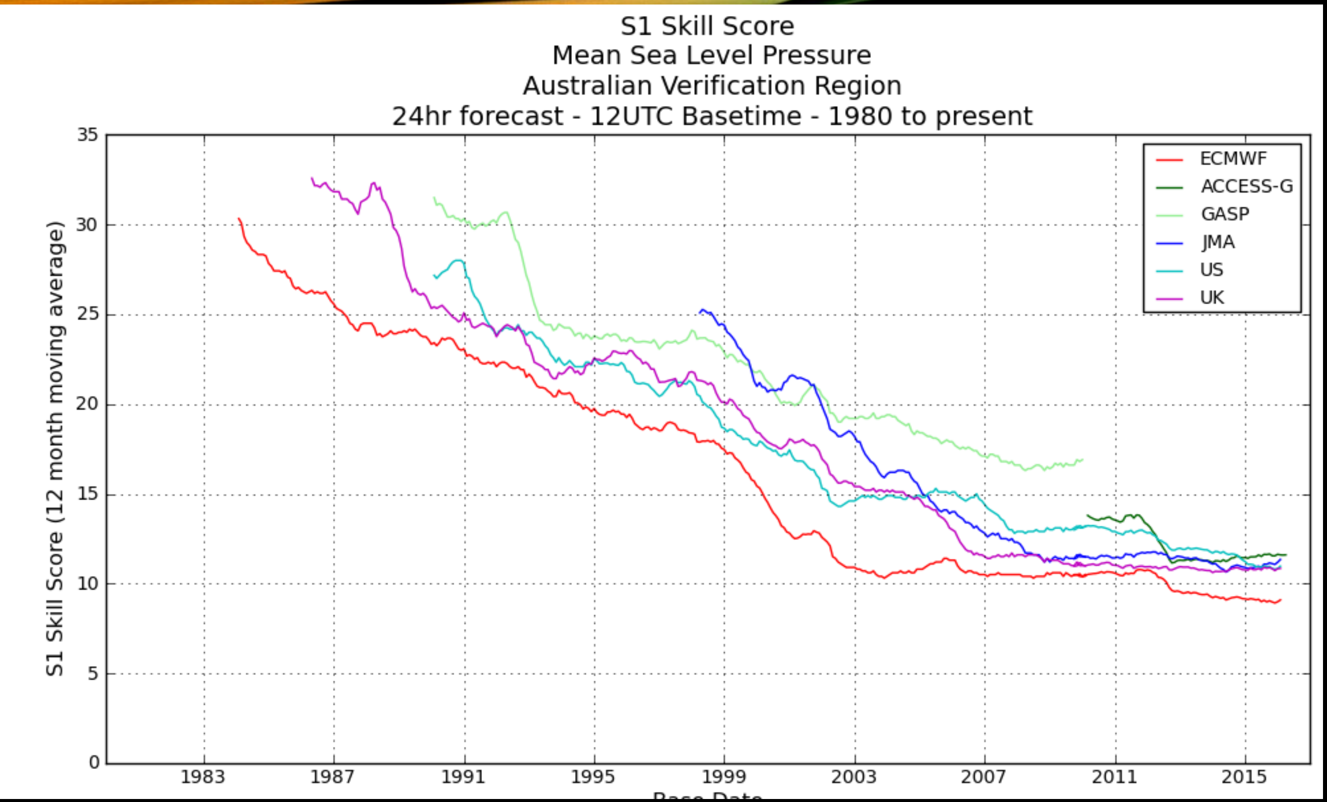
- The great improvement in weather prediction since the 1980s
- The closing of the gap between the skill of forecasts in the northern and southern hemispheres (mainly due to satellite data and improved analysis techniques)



Lead time for acceptable forecasts – Southern Hemisphere Extratropics

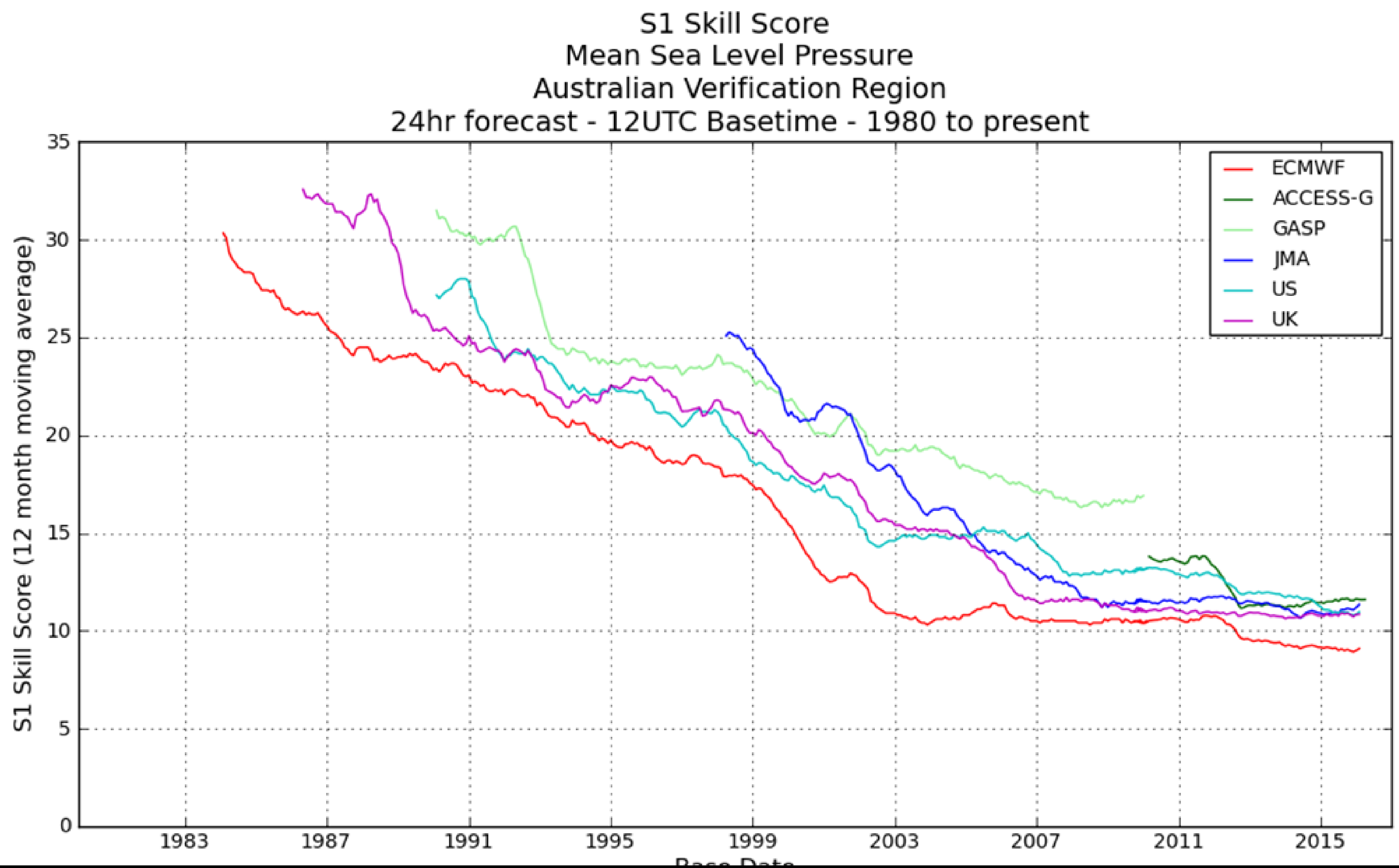


Lead time for acceptable forecasts – Tropics

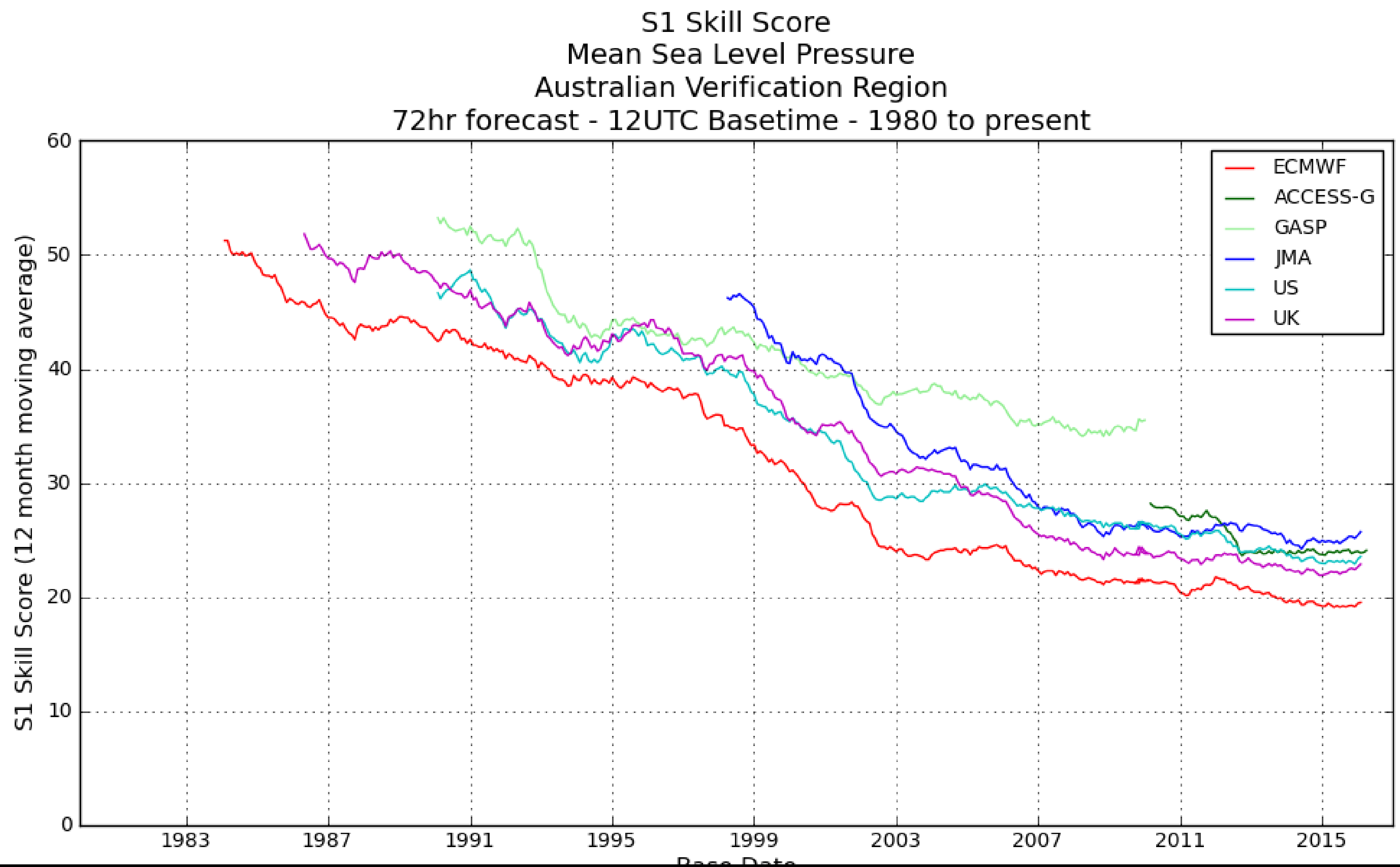


The skill score measures the errors in the forecast weather map – so a lower score is better!

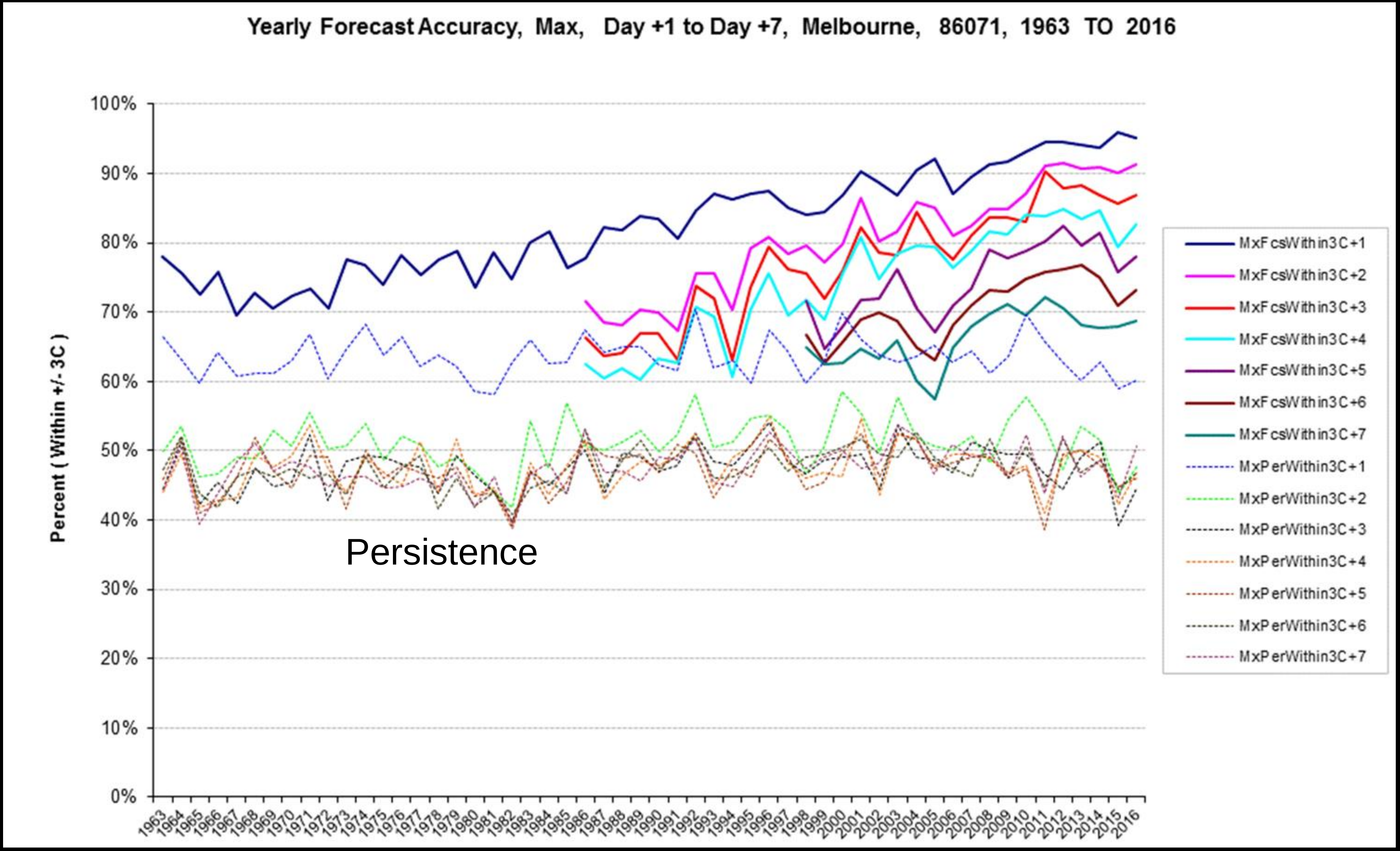
ECMWF – European Centre for Medium Range Weather Forecasts
GASP and ACCESS-G are Australian Bureau of Meteorology
JMA – Japan Meteorological Agency
US – US National Weather Service
UK – United Kingdom Meteorological Office



24 hour forecast “skill” for MSLP in the Australian Region


S1 Skill Score
Mean Sea Level Pressure
Australian Verification Region
72hr forecast - 12UTC Basetime - 1980 to present
S1 Skill Score (12 month moving average)
0
10
20
30
40
50
60
1983
1987
1991
1995
1999
2003
2007
2011
2015
ECMWF
ACCESS-G
GASP
JMA
US
UK

How does the skill of the computer weather prediction translate into accuracy of real life city forecasts?



Percentage of temperature forecasts for Melbourne within 3 degrees – 1963 to 2016

Bureau of Meteorology Forecast Accuracy Information

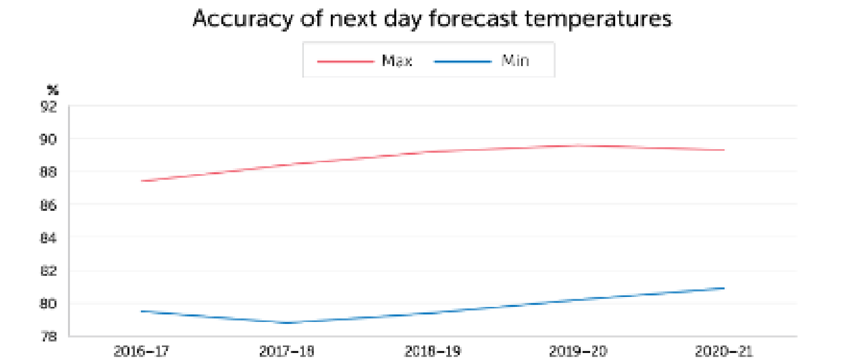
http://www.bom.gov.au/inside/forecast-accuracy.shtml

Temperature forecasts

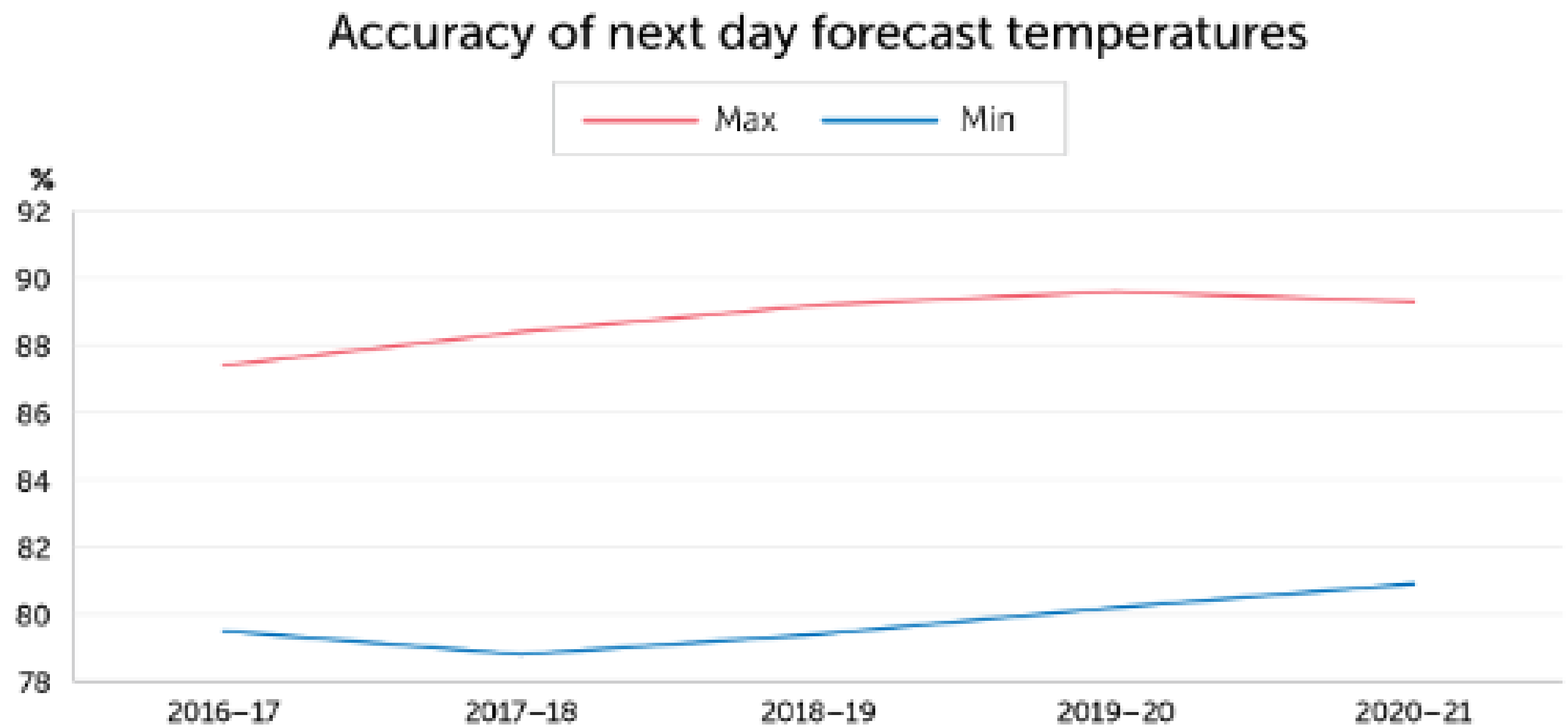
"In 2020–21, the Bureau's maximum temperature forecasts were accurate 89% of the time."

Temperature forecasts are considered accurate if they were within 2 °C of actual temperatures.

Over 2020–21, daily maximum temperature forecasts were accurate 89.3 per cent of the time. Overnight minimum temperature forecasts were accurate 80.9 per cent of the time.



Accuracy of next day forecast temperatures: Forecast maximum and minimum temperatures for the next day across 500 locations that were accurate to within two degrees, showing year-to-year changes.



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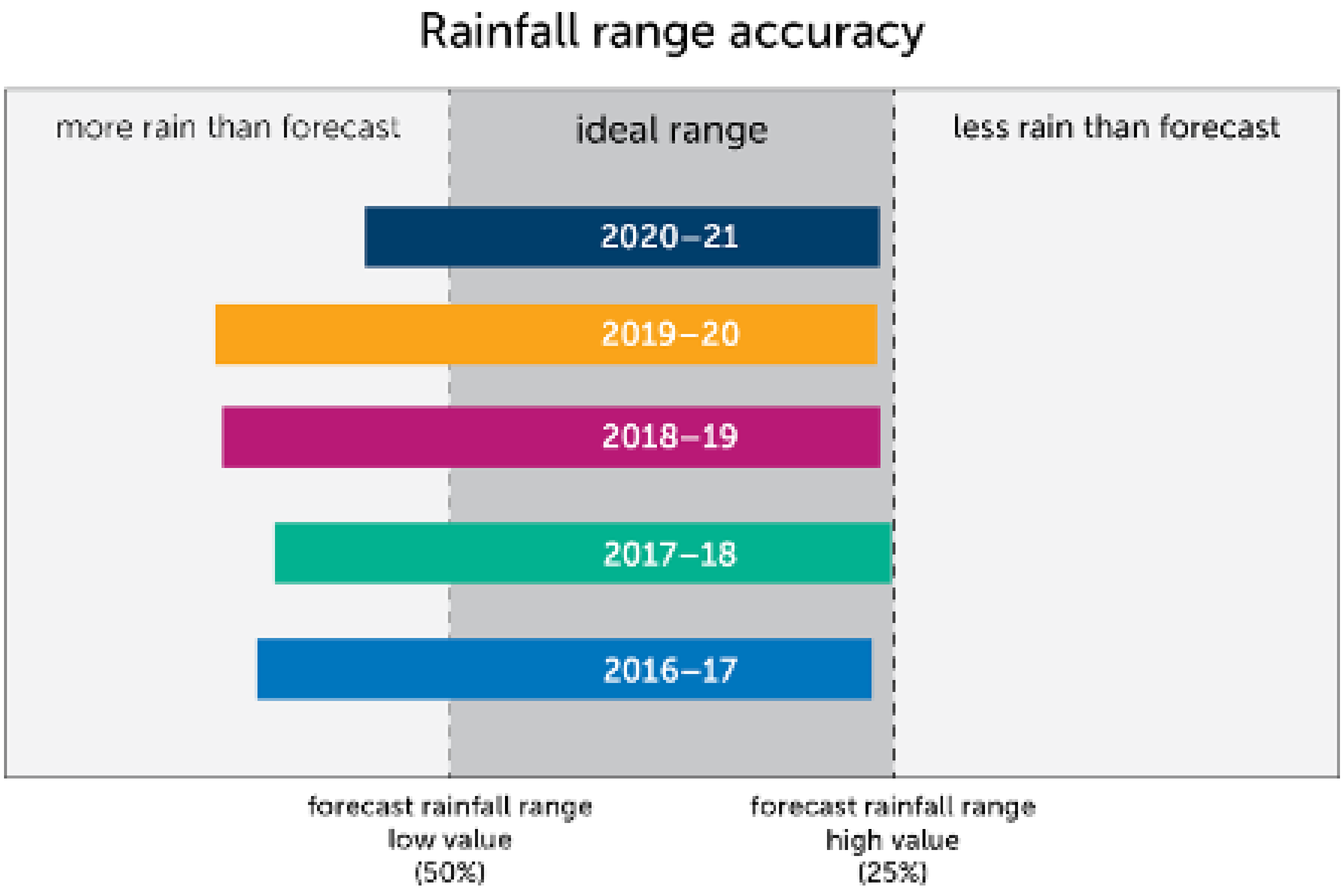
Accuracy of next day forecast temperatures: Forecast maximum and minimum temperatures for the next day across 500 locations that were accurate to within two degrees, showing year-to-year changes.

In 2020–21, the Bureau's forecast rainfall range values provided a good indication of observed rainfall based on statistical performance metrics.



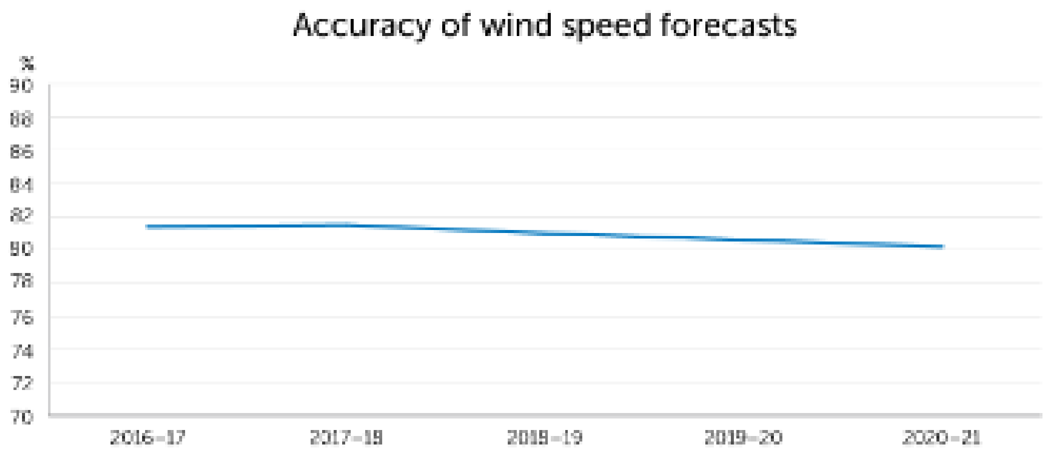
Accuracy of the rainfall range forecast for the next day across 500 locations when compared to observed rainfall.

http://www.bom.gov.au/inside/forecast-accuracy.shtml

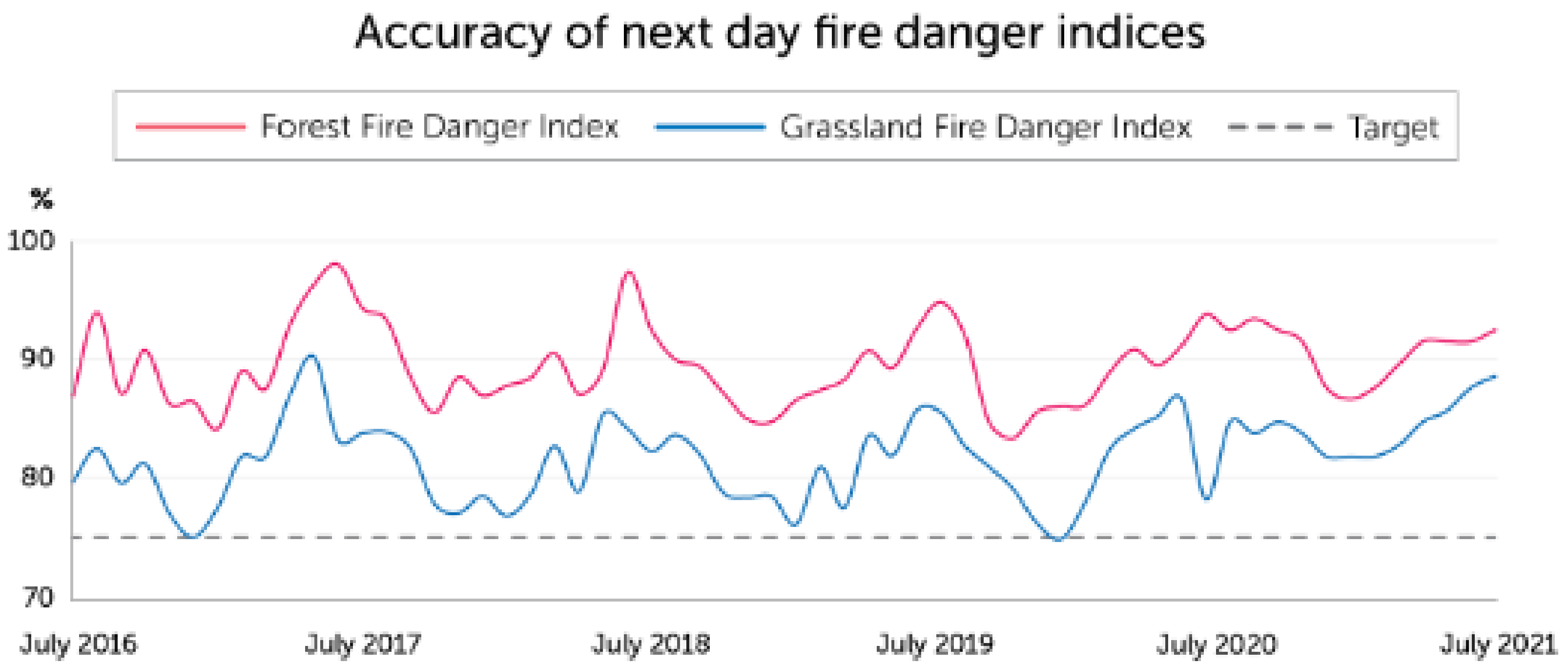
80% of wind speeds are within *5 knots* for Local Waters areas

In 2020–21, for coastal areas, 80.2 per cent of wind forecasts for the next day were correctly predicted to within five knots. When looking across all urban, rural and coastal areas, 82 per cent of forecast wind speeds were within five knots.

94 per cent of marine gale warnings issued for capital city local waters met accuracy standards.



Accuracy of next day wind forecasts for coastal areas: Percentage of wind speed forecasts for the next day across selected coastal locations that were accurate to within 5 knots, showing year-to-year changes.



Accuracy of next day fire danger indices.