

Weather Forecasting: From Woolly Art to Solid Science

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*Talk to the
Irish Meteorological Society*

Acknowledgements

Thanks to

- Irish Meteorological Society (for invitation)
- My Friends and Colleagues in Met Éireann
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The Information Explosion

Where is the wisdom we have lost in knowledge?

Where is the knowledge we have lost in information?

T. S. Eliot (1888-1976)

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We must seek the path from information to knowledge!

We must seek the path from knowledge to wisdom!

Guess Who? (2003)

Outline of Talk

- *Development of Observational Meteorology from Ancient Times*

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- *The ENIAC Integrations (c. 1950)*
Electronic Numerical Integrator And Computer
- *Modern Computer-based Weather Forecasting (c. 2000)*

Observational Meteorology

from Ancient Times

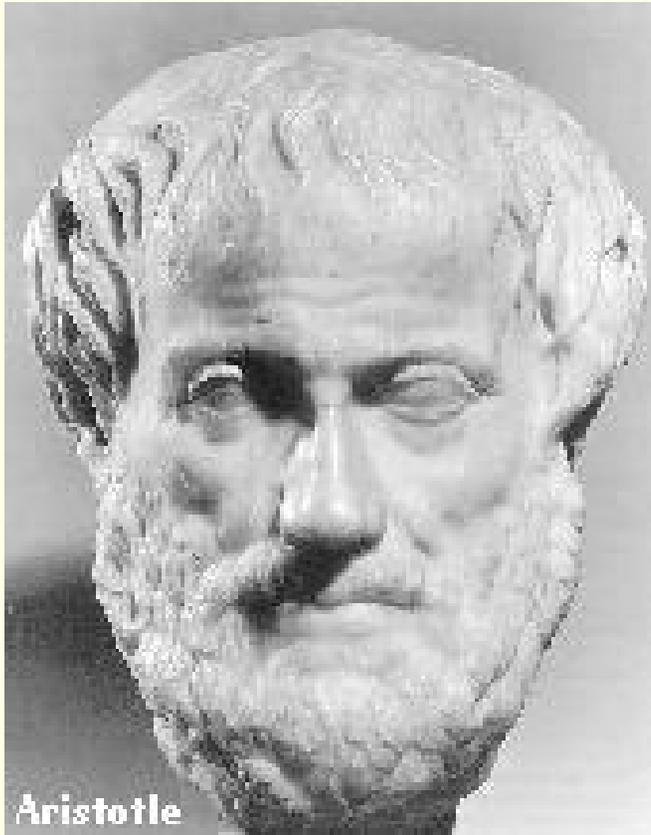
Aristotle's *Meteorologia*

Aristotle (384-322 BC) was a past master at asking questions.

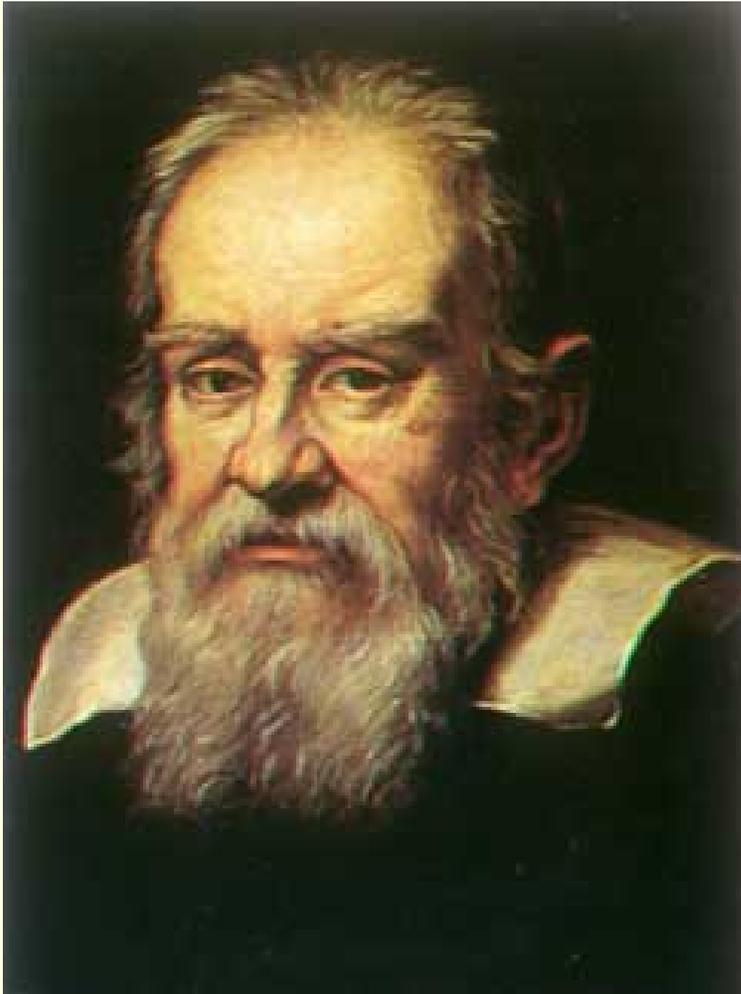
He wrote the first book on Meteorology, the *Μετεωρολογία* (*μετεωρον*: **Something in the air**)

This work dealt with the causes of various weather phenomena and with the origin of comets.

While a masterly speculator, Aristotle was a poor observer: for example, he believed that the **lightning followed the thunder!**



Galileo Galilei (1564–1642)



Galileo formulated the basic law of falling bodies, which he verified by careful measurements.

He constructed a telescope, with which he studied lunar craters, and discovered four moons revolving around Jupiter.

Galileo is credited with the invention of the **Thermometer**.



Galileo in the Money

Galileo's Thermometer



The **Galileo Thermometer** is a popular modern *collectable* and an attractive decoration.

As temperature rises, the fluid expands and its density decreases.

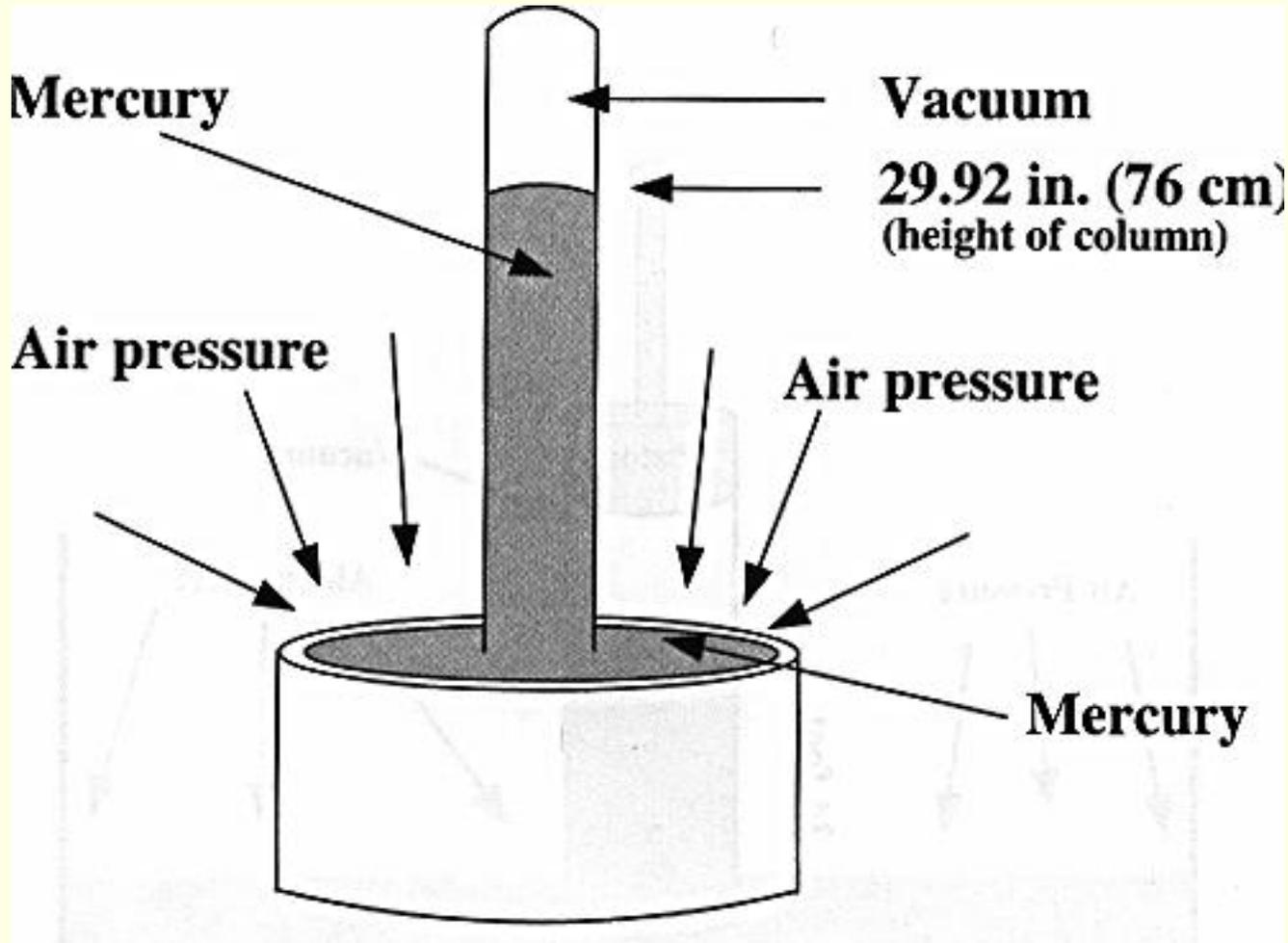
The reduced buoyancy causes the glass baubles to sink, indicating temperature changes.

Torricelli's Barometer

Evangelista Torricelli (1608–1647), a student of Galileo, devised the first accurate **barometer**.



Barometric Pressure



The relationship between the height of the mercury column and the character of the weather was soon noticed.

Isaac Newton (1642-1727)



Newton established the fundamental principles of **Dynamics**.

He formulated the basic law of **Gravitation**.

He produced monumental results in **Celestial Mechanics**.

He laid the foundation for differential and integral **Calculus**.

He made fundamental contributions to **Optics**.

Newton was arguably the **greatest scientist** the world has ever known.

Newton: the Inventor of Science



The Irish writer John Banville, in his work *The Newton Letters*, go so far as to write that 'Newton invented science'.

This is a debatable and thought-provoking claim.

There is a recent biography of Newton by James Gleick.

Newton's Law of Motion

The rate of change of momentum of a body is equal to the sum of the forces acting on the body.

Let m be the mass of the body and \mathbf{V} its velocity. Then the momentum is $\mathbf{p} = m\mathbf{V}$.

If \mathbf{F} is the total applied force, Newton's Second Law gives

$$\frac{d\mathbf{p}}{dt} = \mathbf{F} .$$

The acceleration \mathbf{a} is the rate of change of velocity, that is, $\mathbf{a} = d\mathbf{V}/dt$. If the mass m is constant, we have

$$\mathbf{F} = m\mathbf{a} .$$

Force = Mass \times Acceleration.

Edmund Halley (1656–1742)



Edmund Halley was a contemporary and friend of Isaac Newton.

He was largely responsible for persuading Newton to publish his *Principia Mathematica*.

Edmund Halley (1656–1742)

- Edmund Halley attended Queen's College, Oxford.
- In 1683, he published his theory of the variation of the magnet.
- In 1684, he conferred with Newton about the inverse square law in the solar system.
- In 1686, he wrote on the trade winds and the monsoons.
- He undertook three voyages during 1698–1701, to test his magnetic variation theory.
- Then he became professor of Geometry at Oxford.
- At the age of 64, he invented the diving bell.
- Halley died in Greenwich in 1742.

Halley and his Comet



Halley's analysis of what is now called Halley's comet is an excellent example of the scientific method in action.

Observation:

The comets of 1456, 1531, 1607, and 1682 followed similar orbital paths around the Sun. Each appearance was separated from the previous one by about 76 years.

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Further Confirmation:

Appearances of the comet have since been found in the historic record as far back as 2000 years.

A Tricky Question

If the **Astronomers** can make accurate 76-year forecasts, why can't the **Meteorologists** do the same?

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- Size of the Problem

The solar system is discrete, with relatively **few degrees of freedom**; **Dynamics** is enough.

The atmosphere is a continuum with (effectively) **infinitely many variables**; **Thermodynamics** is essential.

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- Order versus Chaos

The equations of the solar system are quasi-integrable and the **motion is regular**.

The equations of the atmosphere are essentially nonlinear and the **motion is chaotic**.

Euler's Equations for Fluid Flow



Leonhard Euler, born on 15 April, 1707 in Basel. Died on 18 September, 1783 in St Petersburg.

Euler formulated the equations for incompressible, inviscid fluid flow:

$$\frac{\partial \mathbf{V}}{\partial t} + \mathbf{V} \cdot \nabla \mathbf{V} + \frac{1}{\rho} \nabla p = \mathbf{g}.$$
$$\nabla \cdot \mathbf{V} = 0$$

The Navier-Stokes Equations

$$\frac{\partial \mathbf{V}}{\partial t} + \mathbf{V} \cdot \nabla \mathbf{V} + \frac{1}{\rho} \nabla p = \nu \nabla^2 \mathbf{V} + \mathbf{g}^* .$$

The **Navier-Stokes Equations** describe how the change of velocity, the acceleration of the fluid, is determined by the **pressure gradient** force, the **gravitational** force and the **frictional** force.

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For motion relative to the rotating earth, we must include the **Coriolis** force:

$$\frac{\partial \mathbf{V}}{\partial t} + \mathbf{V} \cdot \nabla \mathbf{V} + 2\boldsymbol{\Omega} \times \mathbf{V} + \frac{1}{\rho} \nabla p = \nu \nabla^2 \mathbf{V} + \mathbf{g}.$$

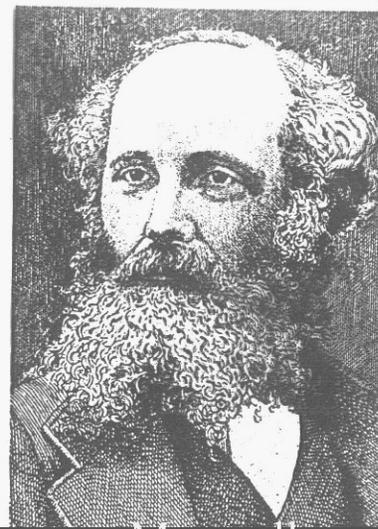
The Hairy Men of Thermo-D



Joule Joule



Boltzmann



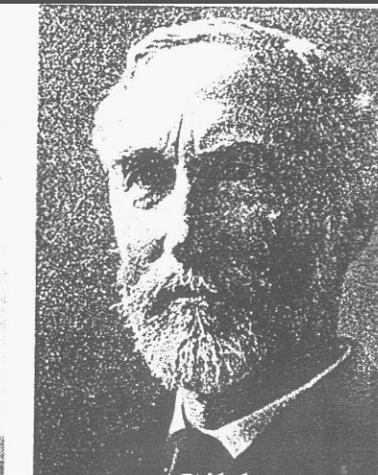
Maxwell



Clausius



Kelvin



Gibbs

It would appear from this sample that a fulsome beard may serve as a thermometer of proficiency in thermodynamics.

However, more exhaustive research is required before a definitive conclusion can be reached.

Physical Laws of the Atmosphere

GAS LAW (Boyle's Law and Charles' Law.)

Relates the pressure, temperature and density

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Conservation of mass; air neither created nor destroyed

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Describe how the change of velocity is determined by the pressure gradient, Coriolis force and friction

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Seven equations; seven variables (u, v, w, ρ, p, T, q).

The Primitive Equations

$$\frac{du}{dt} - \left(f + \frac{u \tan \phi}{a} \right) v + \frac{1}{\rho} \frac{\partial p}{\partial x} + F_x = 0$$

$$\frac{dv}{dt} + \left(f + \frac{u \tan \phi}{a} \right) u + \frac{1}{\rho} \frac{\partial p}{\partial y} + F_y = 0$$

$$p = R\rho T$$

$$\frac{\partial p}{\partial y} + g\rho = 0$$

$$\frac{dT}{dt} + (\gamma - 1)T\nabla \cdot \mathbf{V} = \frac{Q}{c_p}$$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{V} = 0$$

$$\frac{\partial \rho_w}{\partial t} + \nabla \cdot \rho_w \mathbf{V} = [\text{Sources} - \text{Sinks}]$$

Seven equations; seven variables ($u, v, w, p, T, \rho, \rho_w$).

Scientific Weather Forecasting in a Nut-Shell

- The atmosphere is a **physical system**

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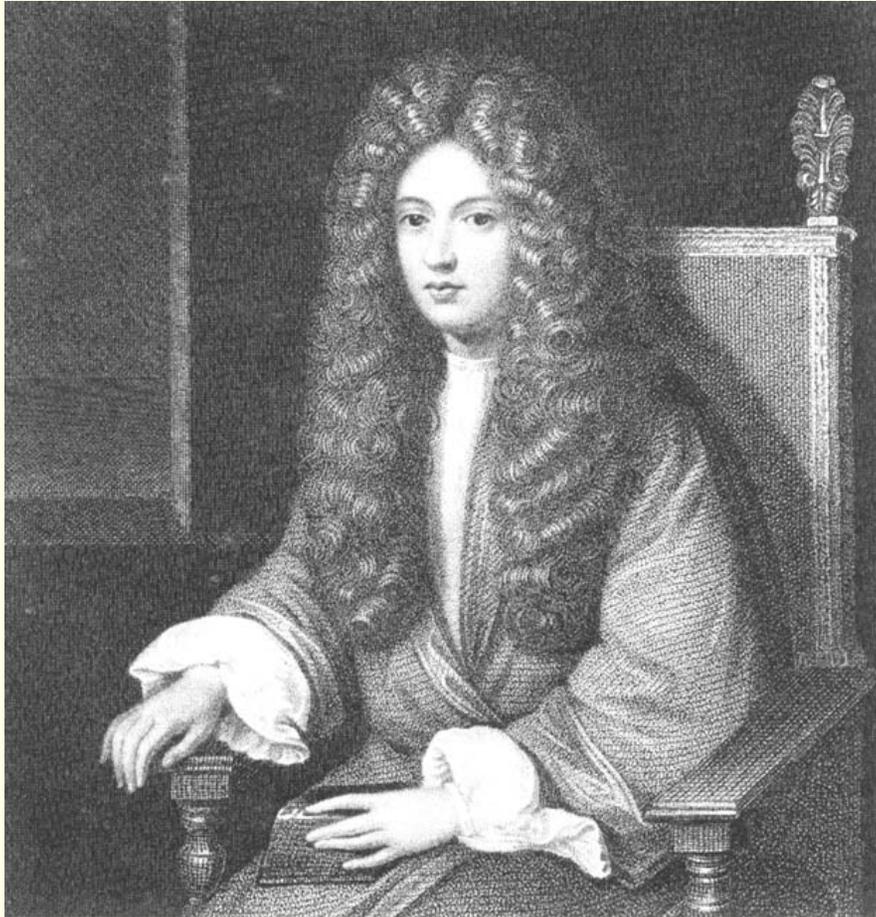
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- The equations are very complicated (non-linear) and a **powerful computer** is required to do the calculations
 - The accuracy decreases as the range increases; there is an inherent **limit of predictability**.

Irish Scientists who have made Contributions to Meteorology

Robert Boyle (1627-1691)



Robert Boyle was born in Lis-
more, Co. Waterford.

He was a founding fellow of
the Royal Society.

Boyle formulated the re-
lationship between pressure
and volume of a fixed mass of
gas at fixed temperature.

$$p \propto 1/V$$

Richard Kirwan (1733–1812)



Richard Kirwan was born in Co. Galway. He grew up at Cregg Castle, which was built in 1648 by the Kirwan family.

He was a noted Chemist, Mineralogist, Meteorologist and Geologist

He was an early President of the Royal Irish Academy

He anticipated the concept of air-masses

He believed that the **Aurora Borealis** resulted from combustion of equatorial air.

Francis Beaufort (1774–1857)

Born near Navan in Co. Meath.
Served in the Royal Navy in the Napoleonic wars.

Helped to establish a telegraph line from Dublin to Galway.

Appointed Hydrographer to the Royal Navy in 1829, a post he held until the age of 81.

Promoted Rear Admiral in 1846.

Knight Commander of the Bath two years later.

Best remembered for his scale for estimating the force of the winds at sea — the **Beaufort scale**.



John Tyndall (1820–1893)



One of the great scientists of the 19th century.

Born in 1820 at Leighlinbridge, Carlow.

Studied with Robert Bunsen in Marburg, 1848.

Associated with the Royal Institution from 1853. Assistant to Michael Faraday.

Published more than 16 books and 145 papers.

Tyndall and the Greenhouse Effect

Tyndall wrote that, without water vapour, the Earth's surface would be *held fast in the iron grip of frost*.

He showed that water vapour, carbon dioxide and ozone are strong absorbers of heat radiation.

This is what we now call the Greenhouse Effect.

Tyndall speculated how changes in water vapour and carbon dioxide could be related to climate change.

The Tyndall Centre for Climate Change Research, recently established at the University of East Anglia in Norwich, is named in his honour.

See article on Tyndall in yesterday's Irish Times.

George G Stokes, 1819–1903



George Gabriel Stokes, **founder of modern hydrodynamics.**

Some Contributions of Stokes to Meteorological Science

- *Stokes' Theorem*
- *Stokes Drag and Stokes' Law*
- *Stokes Drift*
- *Stokes Waves*
- *Campbell-Stokes Sunshine Recorder*
- *Navier-Stokes Equations*

William Thompson (1824–1907)

Sir William Thompson, 1st Baron Kelvin of Largs, born in Belfast.

Among the most brilliant scientists of the 19th century.

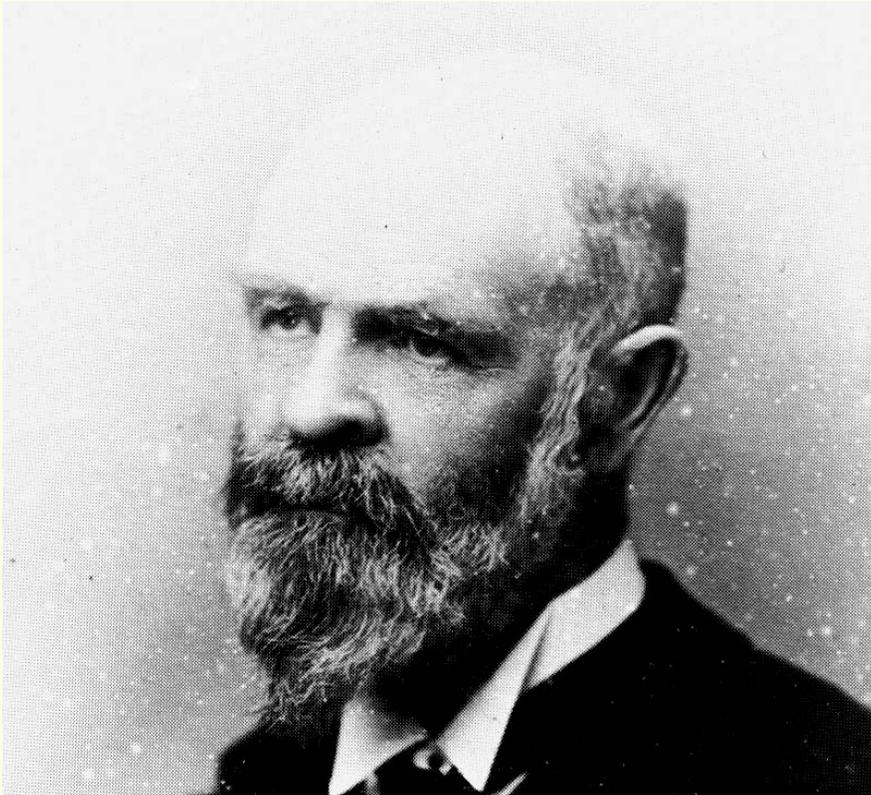
Professor of Natural Philosophy in Glasgow, 1846 (aged 22) – 1899.

Developed the foundations of thermodynamics.

Introduced the absolute scale of temperature, with the zero at -273° .



Robert Henry Scott (1833–1916)



Robert Scott, born in Dublin, 1833.

Founder of Valentia Observatory

First Director of the British Meteorological Office.

With the exception of Kirwan, all these scientists, though born in Ireland, made their names abroad.

All that is about to change!!!

Met Éireann-UCD Link

In October, Met Éireann and University College, Dublin signed an agreement to collaborate in establishing a **Centre for Meteorology and Climatology** at UCD.

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Let's hope that, in future, our Stokes's and Kelvins may not have to leave Ireland to make their marks on meteorology.

The Pre-history of Numerical Weather Prediction (c. 1900)

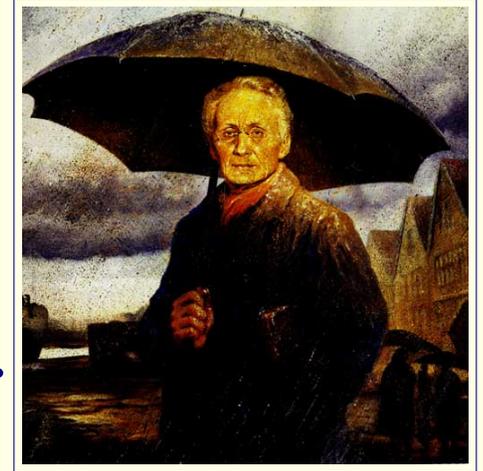
Vilhelm Bjerknes and Lewis Fry Richardson

Vilhelm Bjerknes (1862–1951)



Vilhelm Bjerknes (1862–1951)

- Born March, 1862.
- Matriculated in 1880.
- Fritjøf Nansen was a fellow-student.
- Paris, 1889–90. Studied under Poincare.
- Bonn, 1890–92. Worked with Heinrich Hertz.
- Stockholm, 1893–1907.
 - 1898: Circulation theorems
 - **1904: Meteorological Manifesto**
- Christiania (Oslo), 1907–1912.
- Leipzig, 1913–1917.
- Bergen, 1917–1926.
 - **1919: Frontal Cyclone Model.**
- Oslo, 1926 — (retired 1937).
 - Died, April 9, 1951.



Vilhelm Bjerknes

Bjerknes' 1904 Manifesto

To establish a science of meteorology, with the aim of predicting future states of the atmosphere from the present state.

“If it is true, as every scientist believes, that subsequent atmospheric states develop from the preceding ones according to physical law, then it is apparent that the necessary and sufficient conditions for the rational solution of forecasting problems are the following:

1. A sufficiently accurate knowledge of the **state** of the atmosphere at the initial time
2. A sufficiently accurate knowledge of the **laws** according to which one state of the atmosphere develops from another.”

Step (1) is **Diagnostic**. Step (2) is **Prognostic**.

Graphical v. Numerical Approach

Bjerknes ruled out analytical solution of the mathematical equations, due to their nonlinearity and complexity:

“For the solution of the problem in this form, **graphical or mixed graphical and numerical methods** are appropriate, which methods must be derived either from the partial differential equations or from the dynamical-physical principles which are the basis of these equations.”

However, there was a scientist more bold — or foolhardy — than Bjerknes, who actually tried to calculate future weather. This was **Lewis Fry Richardson**

Lewis Fry Richardson, 1881–1953.





- Born, 11 October, 1881, Newcastle-upon-Tyne
- Family background: well-known quaker family
- 1900–1904: Kings College, Cambridge
- 1913–1916: Met. Office. Superintendent, Eskdalemuir Observatory
- Resigned from Met Office in May, 1916. Joined Friends' Ambulance Unit.
- 1919: Re-employed by Met. Office
- 1920: M.O. linked to the Air Ministry. LFR Resigned, on grounds of conscience
- **1922:** *Weather Prediction by Numerical Process*
- 1926: Break with Meteorology. Worked on Psychometric Studies. Later on Mathematical causes of Warfare
- 1940: Resigned to pursue “peace studies”
- Died, September, 1953.

Richardson contributed to **Meteorology, Numerical Analysis, Fractals, Psychology and Conflict Resolution.**

The Finite Difference Scheme

The globe is divided into cells, like the checkers of a chess-board.

Spatial derivatives are replaced by finite differences:

$$\frac{df}{dx} \rightarrow \frac{f(x + \Delta x) - f(x - \Delta x)}{2\Delta x}.$$

Similarly for time derivatives:

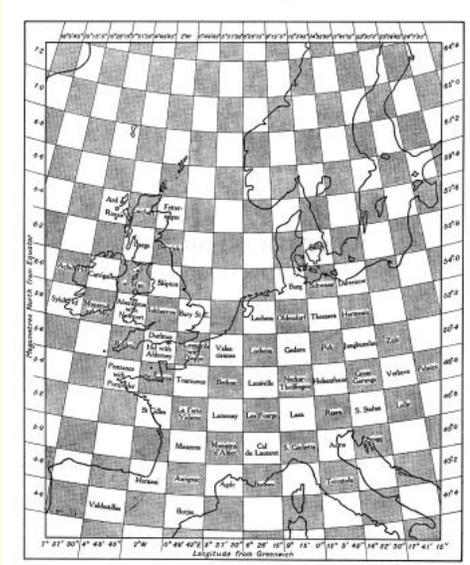
$$\frac{dQ}{dt} \rightarrow \frac{Q^{n+1} - Q^{n-1}}{2\Delta t} = F^n$$

This can immediately be solved for Q^{n+1} :

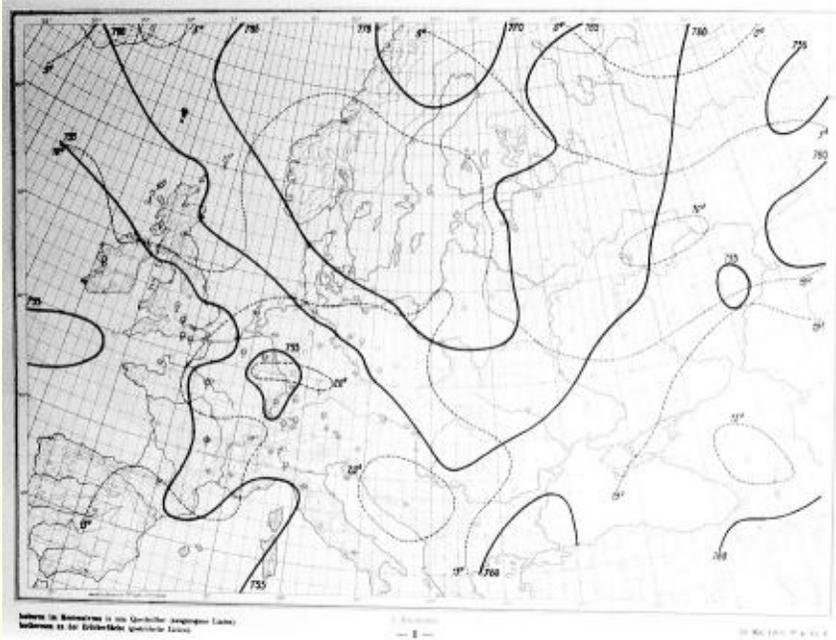
$$Q^{n+1} = Q^{n-1} + 2\Delta t F^n.$$

By repeating the calculations for many time steps, we can get a forecast of any length.

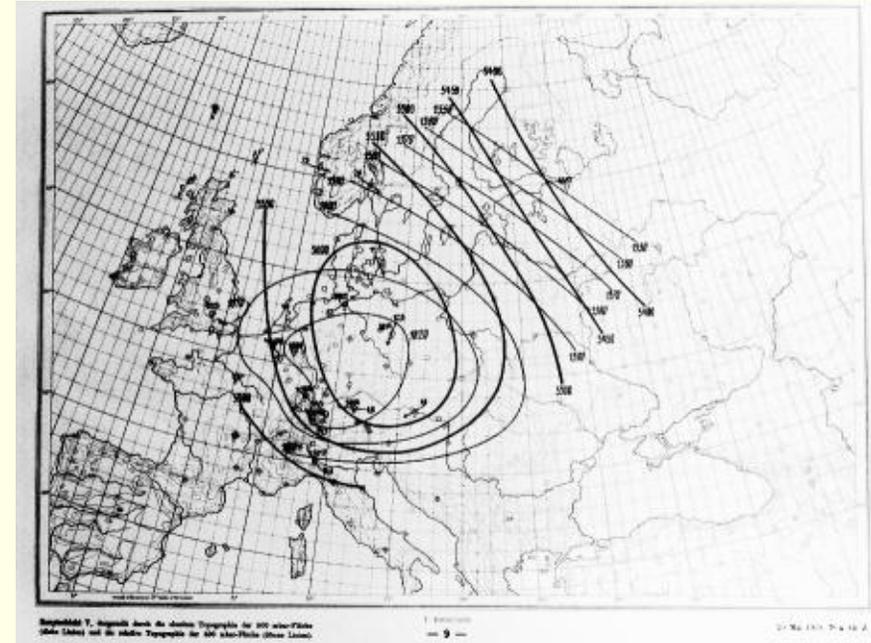
Richardson calculated **only the initial rates of change.**



The Leipzig Charts for 0700 UTC, May 20, 1910



Bjerknes' sea level pressure analysis.



Bjerknes' 500 hPa height analysis.

Some of the initial data for Richardson's "forecast".

Richardson's *Spread-sheet*

COMPUTING FORM P XIII. Divergence of horizontal momentum-per-area. Increase of pressure

The equation is typified by: $-\frac{\partial R_{ps}}{\partial t} = \frac{\partial M_{Eps}}{\partial e} + \frac{\partial M_{Nps}}{\partial n} - M_{Nps} \frac{\tan \phi}{a} + m_{ps} - m_{ps}^* + \frac{2}{a} M_{Eps}$. (See Ch. 4/2#5.)

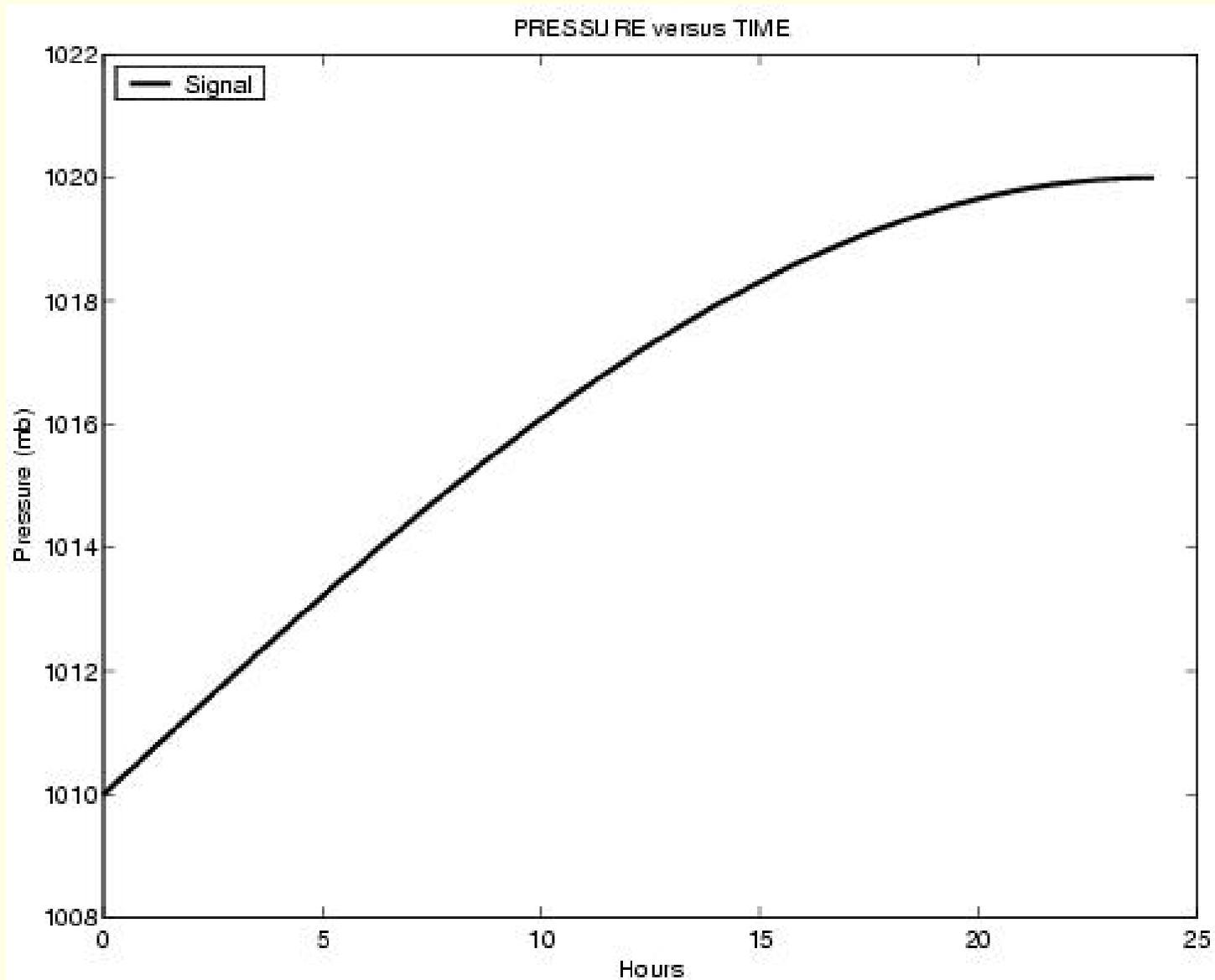
* In the equation for the lowest stratum the corresponding term $-m_{ps}$ does not appear

Longitude 11° East $\delta e = 441 \times 10^5$			Latitude 5400 km North $\delta n = 400 \times 10^5$			Instant 1910 May 20 ^d 7 ^h G.M.T. $a^{-1} \cdot \tan \phi = 1.78 \times 10^{-9}$		Interval, δt 6 hours $a = 6.36 \times 10^8$				
REF.:-			previous 3 columns	previous column		Form P xvi	Form P xvi	equation above	previous column	previous column	previous column	
h	$\frac{\delta M_E}{\delta e}$	$\frac{\delta M_N}{\delta n}$	$-\frac{M_N \tan \phi}{a}$	$\text{div}'_{EN} M$	$-g \delta t \text{div}'_{EN} M$	m_R	$\frac{2M_R}{a}$	$-\frac{\partial R}{\partial t}$	$+\frac{\partial R}{\partial t} \delta t$	$g \frac{\partial R}{\partial t} \delta t$	$\frac{\partial p}{\partial t} \delta t$	
	$10^{-5} \times$	$10^{-5} \times$	$10^{-5} \times$	$10^{-5} \times$	$100 \times$	$10^{-5} \times$	$10^{-5} \times$	$10^{-5} \times$		$100 \times$	$100 \times$	
h_0	-61	-245	-6	-312	656	0		-229	49.5	483	0	
h_2	367	-257	2	112	-236	-83		-136	29.4	287	483	
h_4	93	-303	-16	-226	478	165		-124	26.8	262	770	
h_6	32	-55	-12	-35	74	63		-110	23.8	233	1032	
h_8	-256	38	-8	-226	479	138		-88	19.0	186	1265	
h_{10}											1451	
	NOTE: $\text{div}'_{EN} M$ is a contraction for $\frac{\delta M_E}{\delta e} + \frac{\delta M_N}{\delta n} - M_N \frac{\tan \phi}{a}$				SUM = 1451 $= \frac{\partial p_a}{\partial t} \delta t$	Leave the subsequent columns to be filled up after the vertical velocity has been computed on Form P xvi						check by $\Sigma -g \delta t \text{div}'_{EN} M$

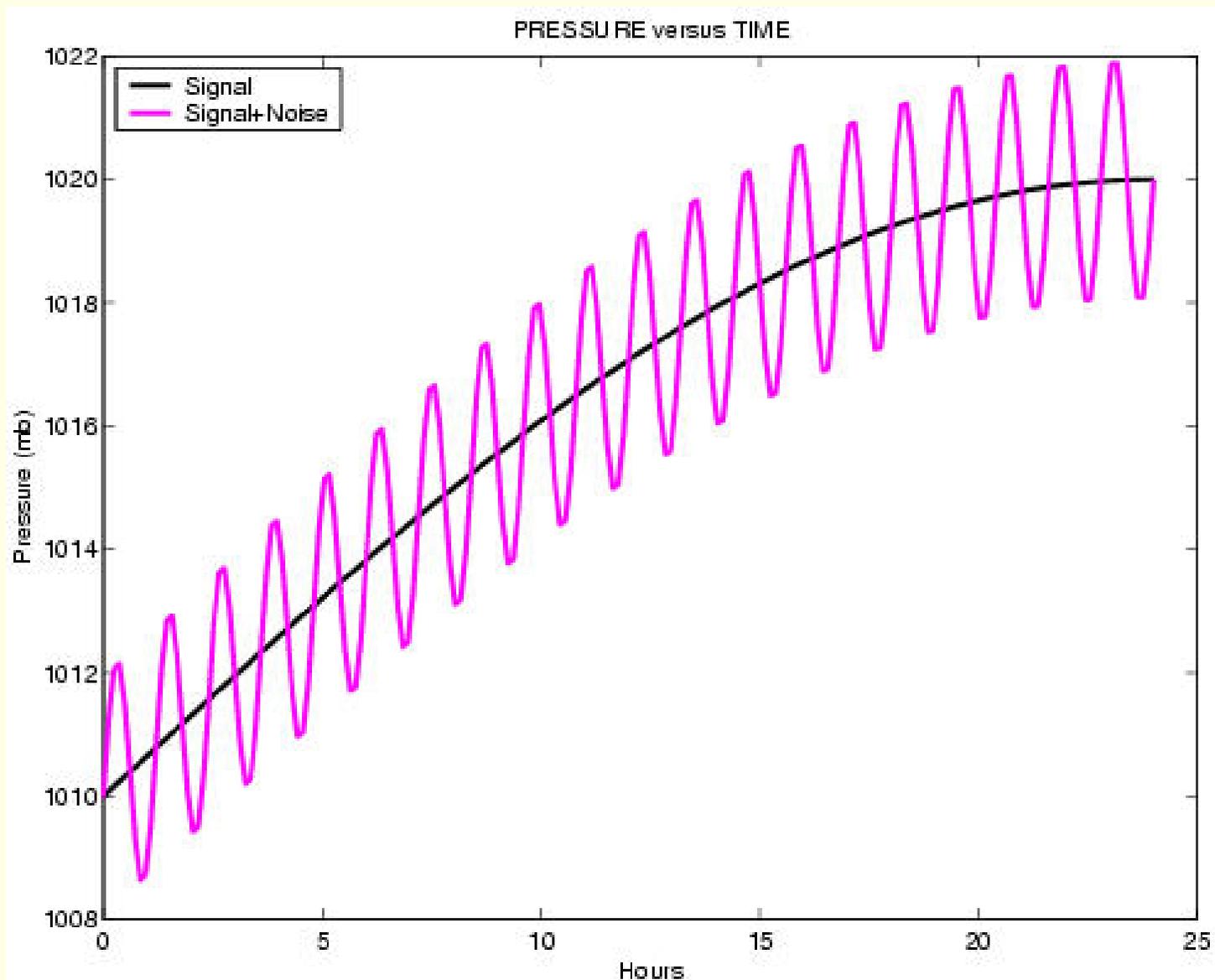
Richardson's Computing Form P_{XIII}

The figure in the bottom right corner is the forecast change in surface pressure: **145 mb in six hours!**

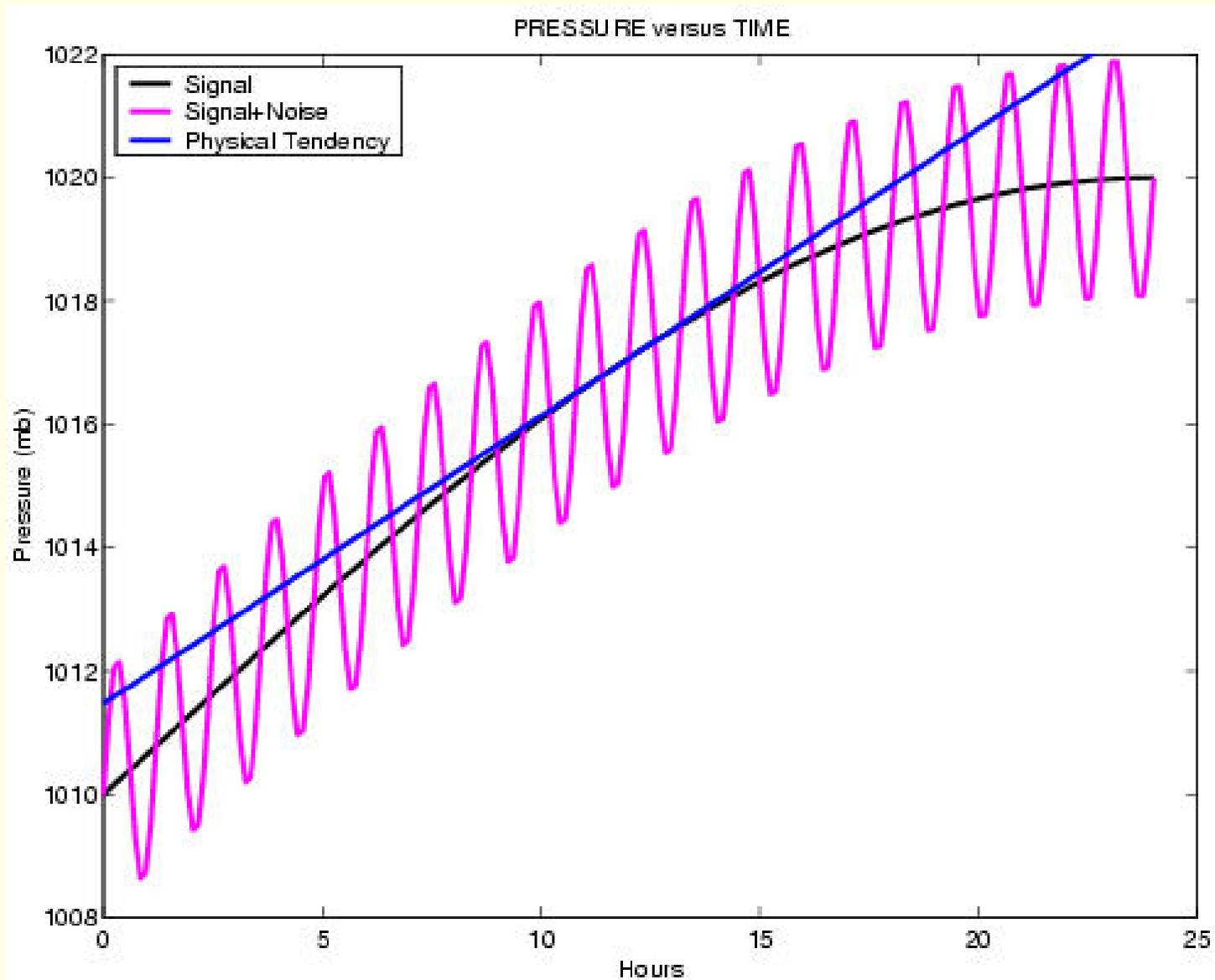
Smooth Evolution of Pressure



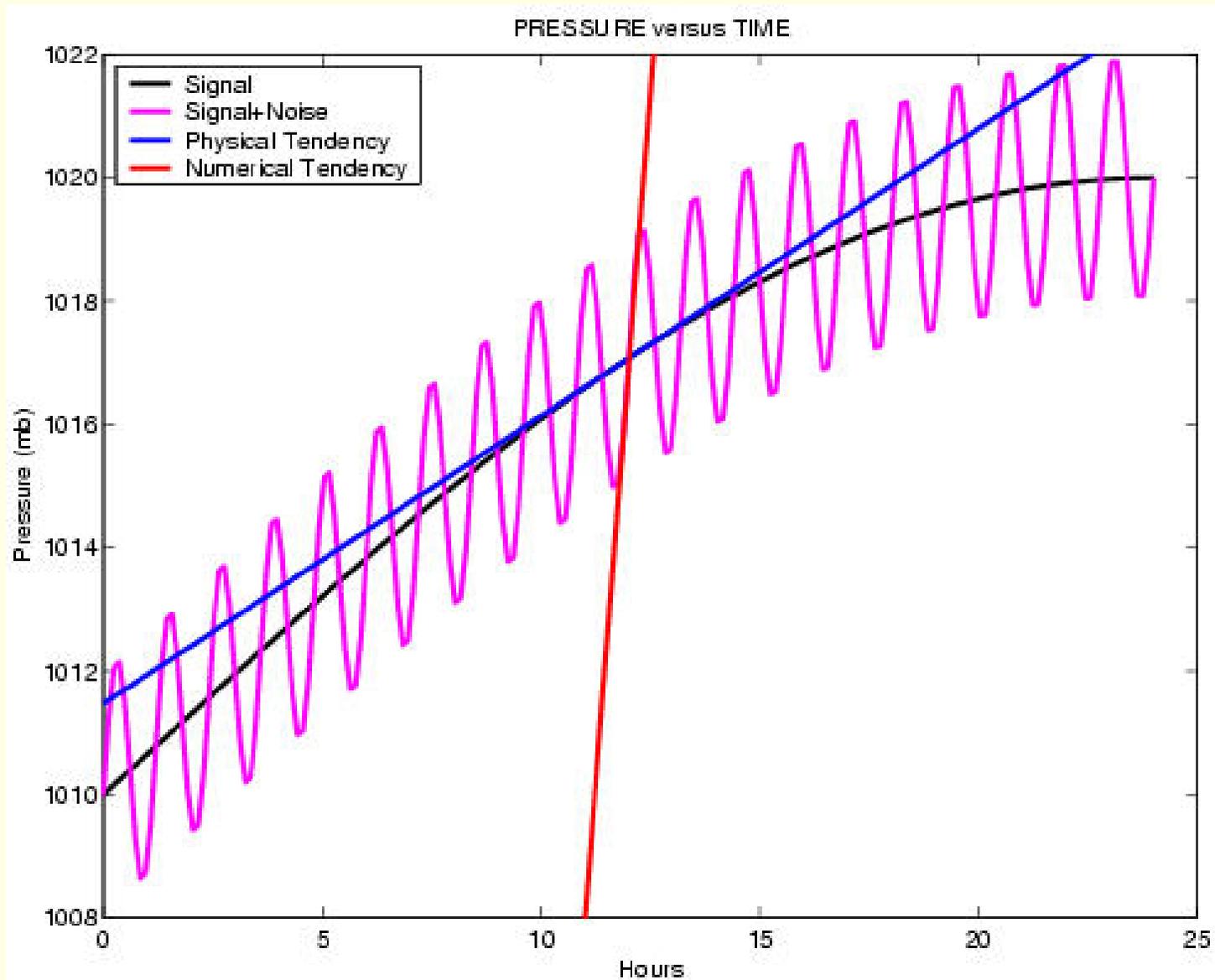
Noisy Evolution of Pressure

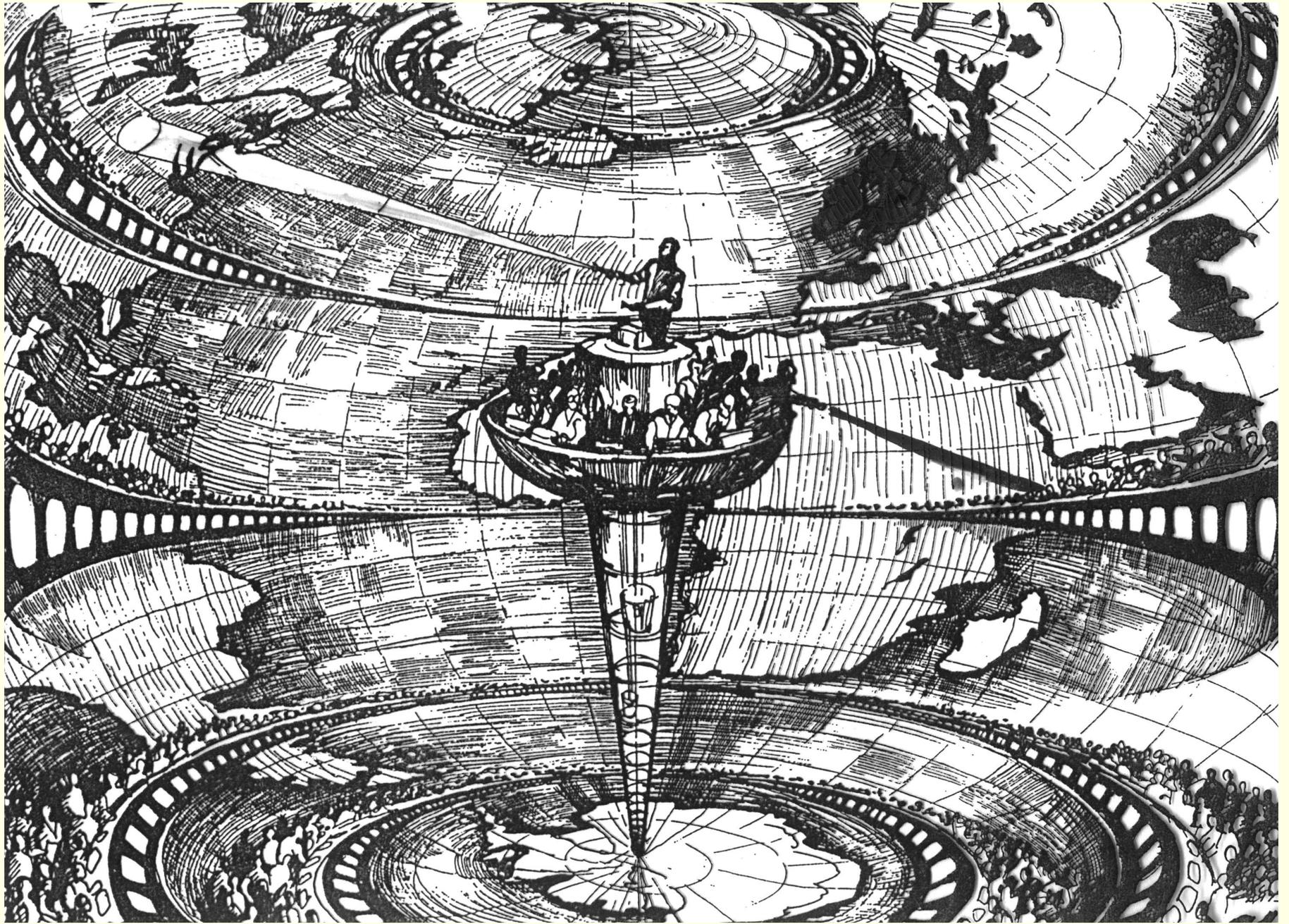


Tendency of a Smooth Signal

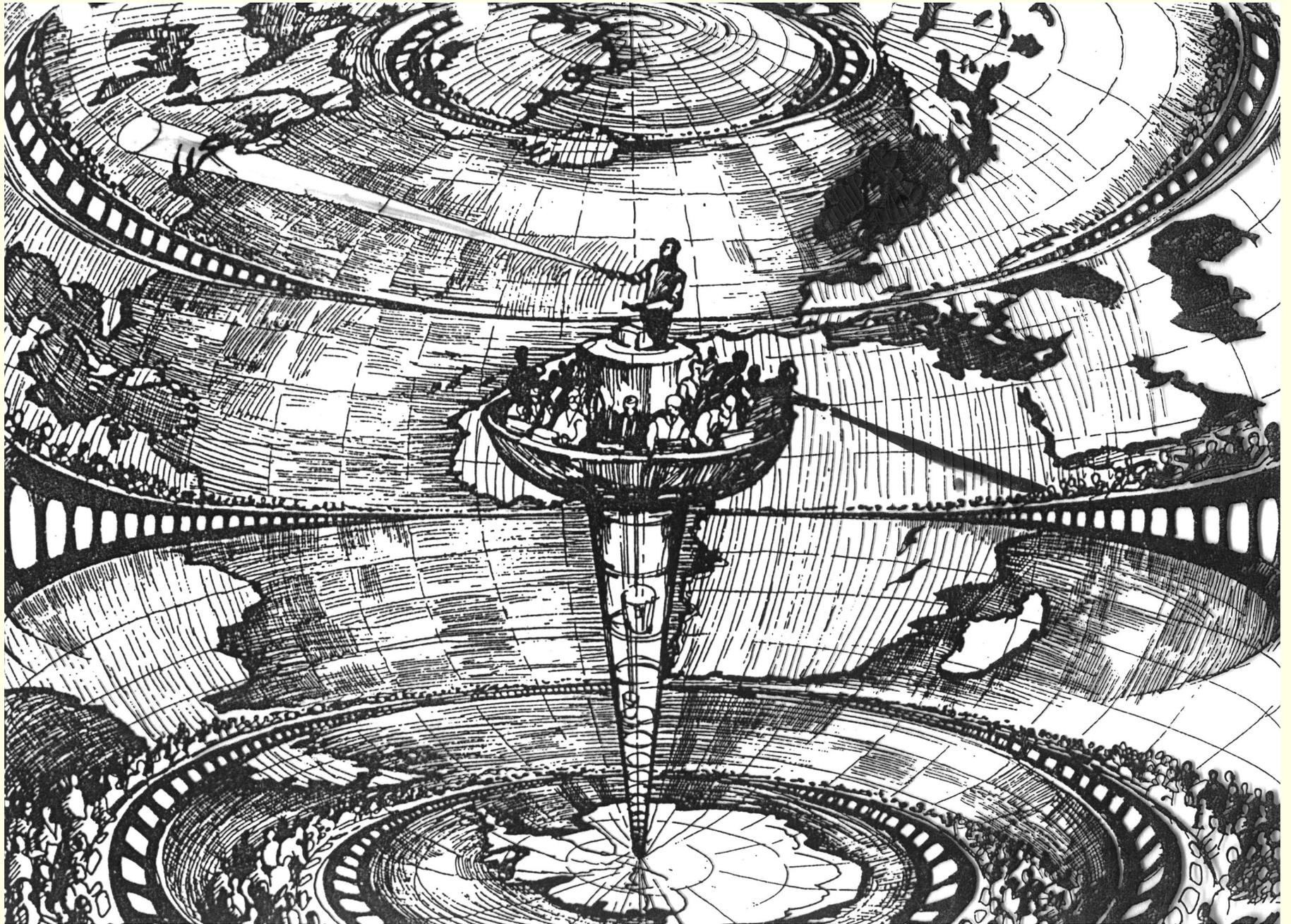


Tendency of a Noisy Signal





Richardson's Forecast Factory (A. Lannerback).
Dagens Nyheter, Stockholm. Reproduced from L. Bengtsson, *ECMWF*, 1984



Richardson's Forecast Factory (A. Lannerback).
Dagens Nyheter, Stockholm. Reproduced from L. Bengtsson, *ECMWF*, 1984

64,000 Computers: The first Massively Parallel Processor

Advances 1920–1950

■ *Dynamic Meteorology*

- Rossby Waves
- Quasi-geostrophic Theory
- Baroclinic Instability

■ *Numerical Analysis*

- CFL Criterion

■ *Atmospheric Observations*

- Radiosonde

■ *Electronic Computing*

- ENIAC

The ENIAC Integrations

(ENIAC: Electronic Numerical Integrator and Computer)

Electronic Computer Project, 1946 (under direction of John von Neumann)

Von Neumann's idea:

Weather forecasting was, *par excellence*, a scientific problem suitable for solution using a large computer.

The objective of the project was to study the problem of predicting the weather by simulating the dynamics of the atmosphere using a digital electronic computer.

A Proposal for funding listed three “possibilities”:

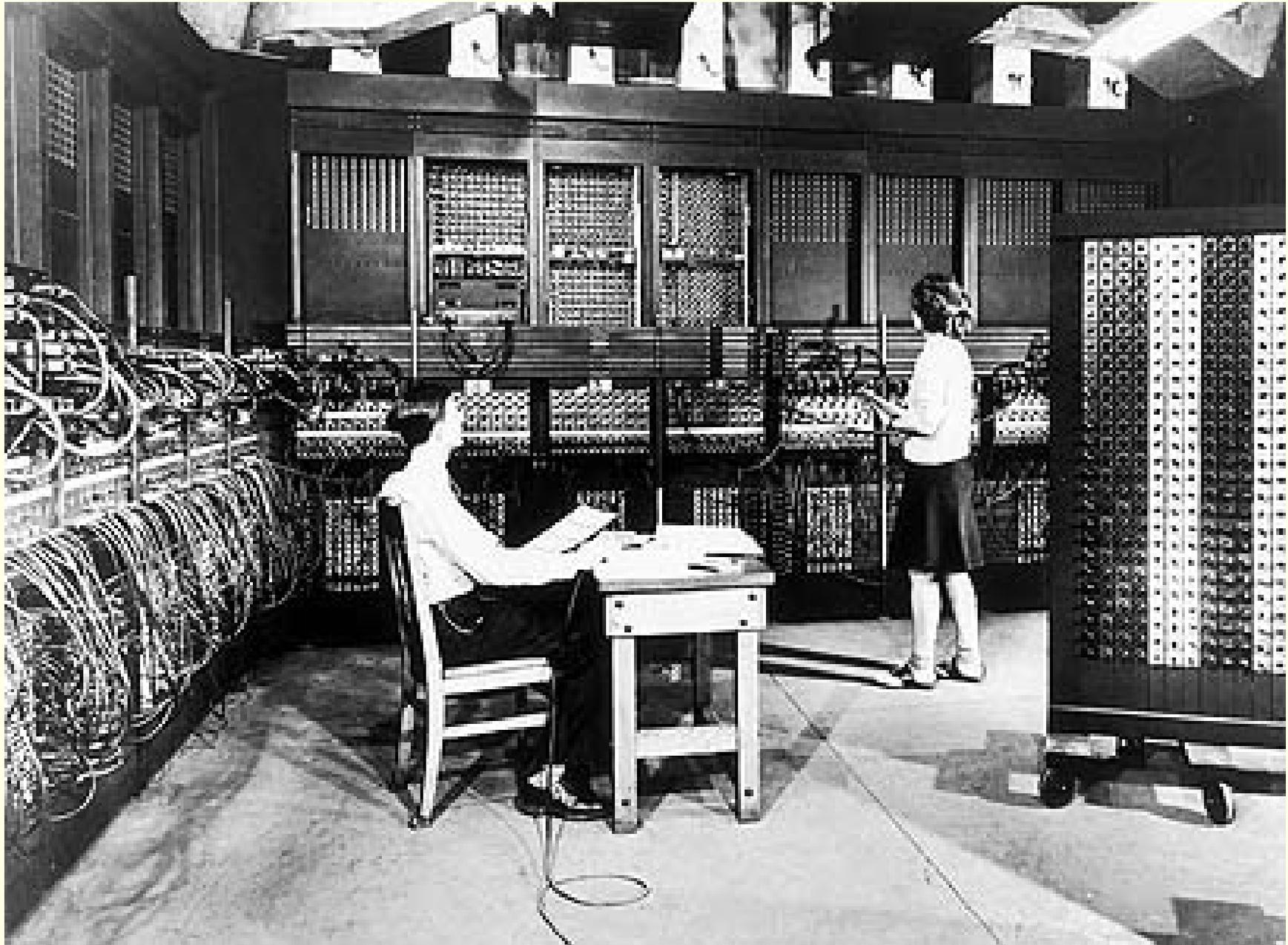
1. Entirely **new methods** of weather prediction by calculation will have been made possible;
2. A new **rational basis** will have been secured for the planning of physical measurements and field **observations**;
3. The first step towards **influencing the weather** by rational human intervention will have been made.

“Conference on Meteorology”

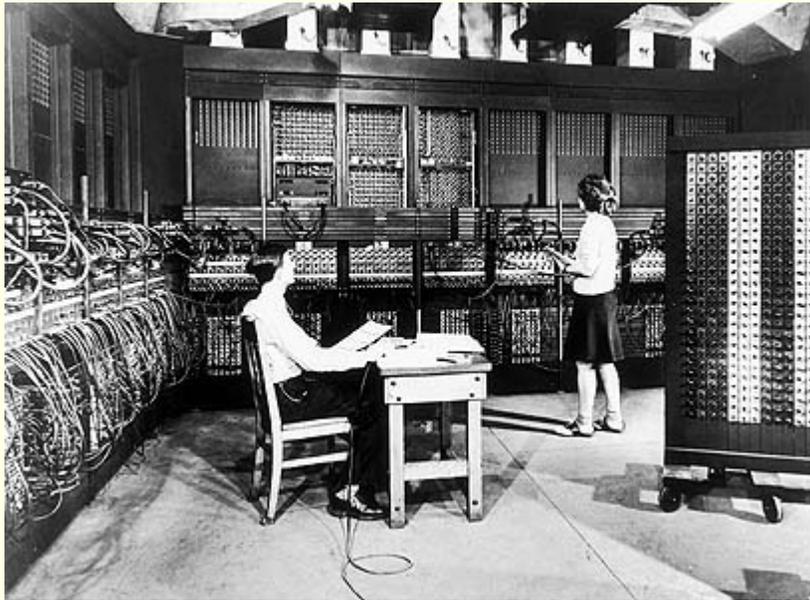
A “Conference on Meteorology” was arranged in the Institute for Advanced Studies (IAS), Princeton on 29–30 August, 1946. Participants included:

- Carl Gustav Rossby
- Jule Charney
- George Platzman
- Norman Phillips
- Ragnar Fjørtoft
- Arnt Eliassen
- Joe Smagorinsky
- Phil Thompson

The ENIAC



The ENIAC



The **ENIAC** (Electronic Numerical Integrator and Computer) was the first multi-purpose programmable electronic digital computer.

It had:

- 18,000 vacuum tubes
- 70,000 resistors
- 10,000 capacitors
- 6,000 switches

Power Consumption: 140 kWatts

The ENIAC: Technical Details.

ENIAC was a **decimal machine**. No high-level language.
Assembly language. Fixed-point arithmetic: $-1 < x < +1$.
10 registers, that is,

Ten words of high-speed memory.

Function Tables:

624 6-digit words of “ROM”, set on
ten-pole rotary switches.

“Peripheral Memory”:

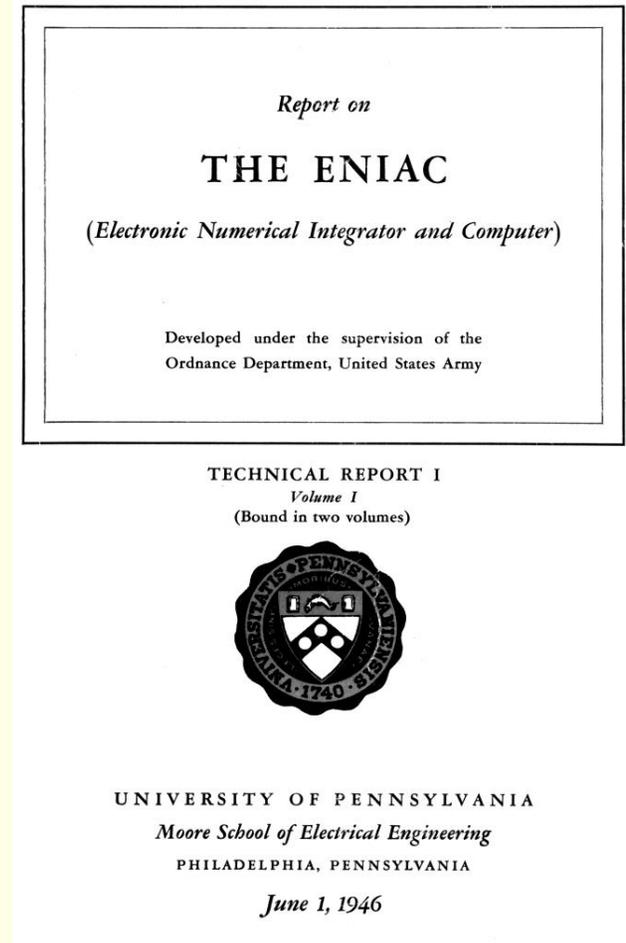
Punch-cards.

Speed: FP multiply: 2ms
(say, **500 Flops**).

Access to Function Tables: **1ms.**

Access to Punch-card equipment:

You can imagine!



Evolution of the Project:

- **Plan A: Integrate the Primitive Equations**

Problems similar to Richardson's would arise

Evolution of the Project:

- **Plan A: Integrate the Primitive Equations**

Problems similar to Richardson's would arise

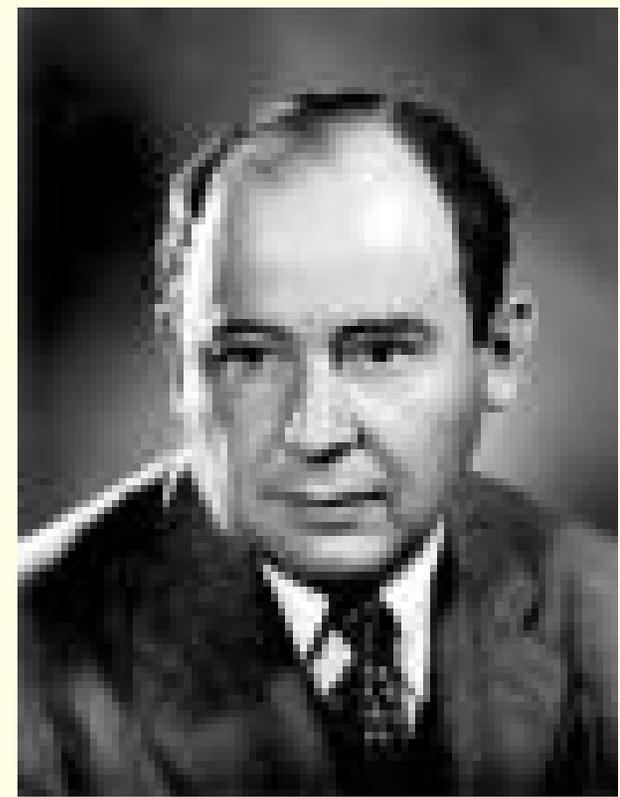
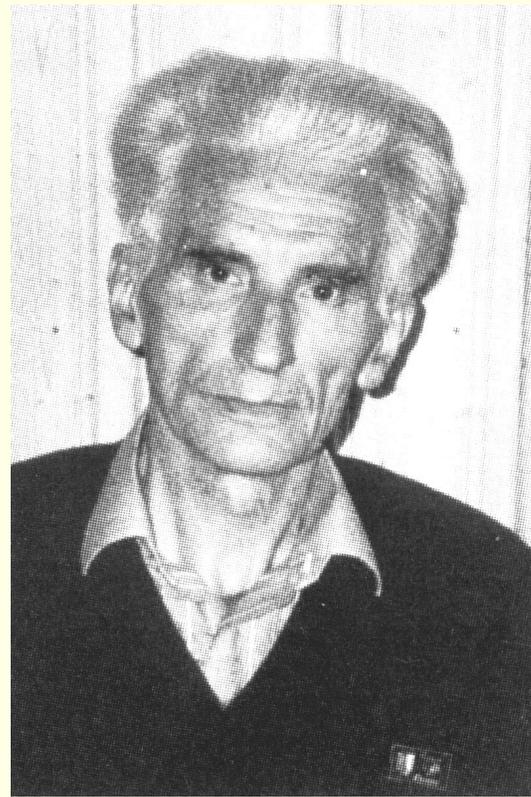
- **Plan B: Integrate baroclinic Q-G System**

Too computationally demanding

Evolution of the Project:

- **Plan A: Integrate the Primitive Equations**
Problems similar to Richardson's would arise
- **Plan B: Integrate baroclinic Q-G System**
Too computationally demanding
- **Plan C: Solve barotropic vorticity equation**
Very satisfactory initial results

Charney, Fjørtoft, von Neumann



Charney, et al., *Tellus*, 1950.

$$\left[\begin{array}{c} \text{Absolute} \\ \text{Vorticity} \end{array} \right] = \left[\begin{array}{c} \text{Relative} \\ \text{Vorticity} \end{array} \right] + \left[\begin{array}{c} \text{Planetary} \\ \text{Vorticity} \end{array} \right] \quad \eta = \zeta + f.$$

The atmosphere is treated as a single layer, and the flow is assumed to be nondivergent. **Absolute vorticity is conserved** following the flow.

$$\frac{d(\zeta + f)}{dt} = 0.$$

This equation looks deceptively simple. But it is **nonlinear**:

$$\frac{\partial \zeta}{\partial t} + \mathbf{V} \cdot \nabla(\zeta + f) = 0.$$

Or, in more detail:

$$\frac{\partial}{\partial t}[\nabla^2 \psi - F\psi] + \left\{ \frac{\partial \psi}{\partial x} \frac{\partial \nabla^2 \psi}{\partial y} - \frac{\partial \psi}{\partial y} \frac{\partial \nabla^2 \psi}{\partial x} \right\} + \beta \frac{\partial \psi}{\partial x} = 0,$$

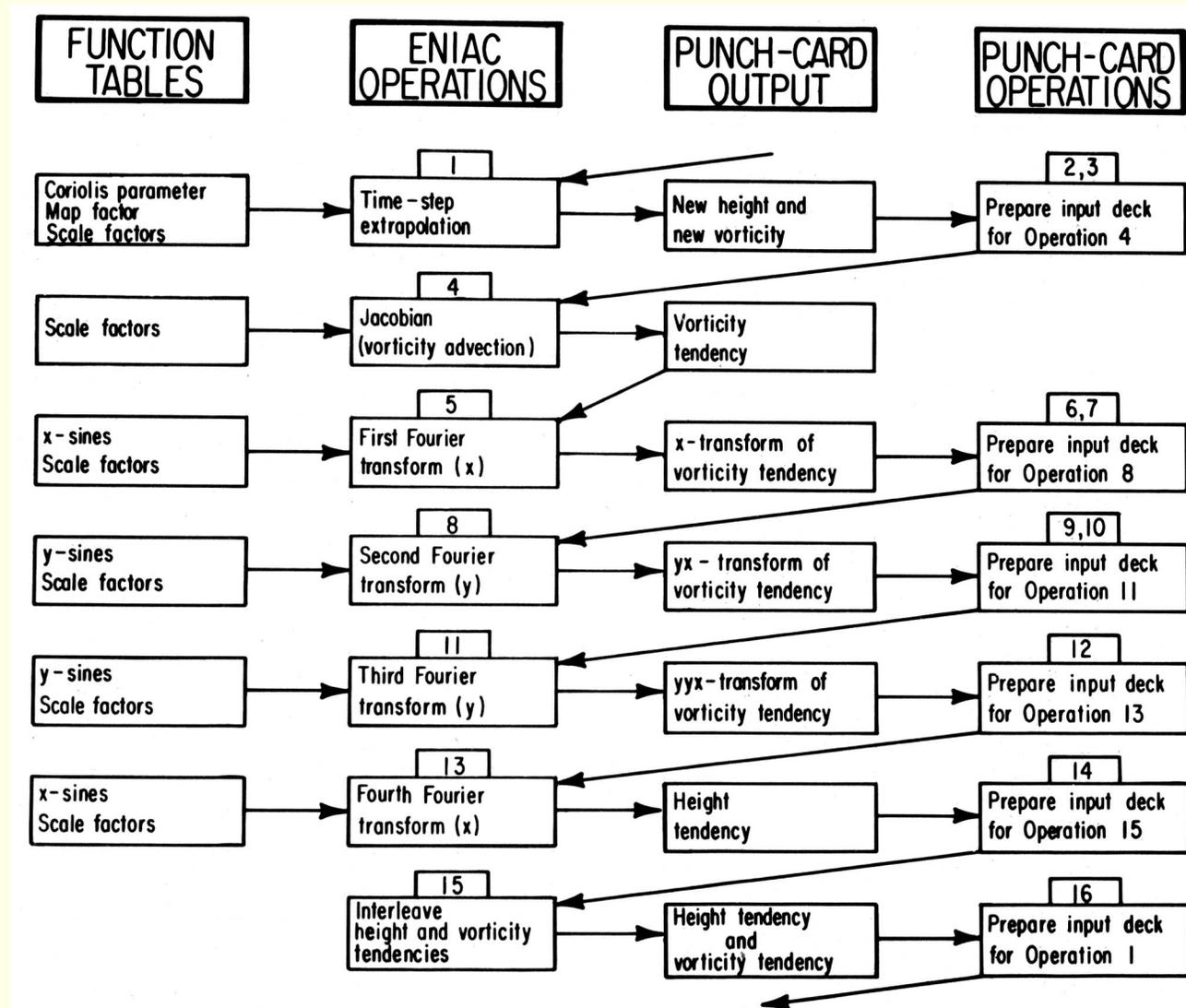
Solution method for BPVE

$$\frac{\partial \zeta}{\partial t} = \mathbf{J}(\psi, \zeta + f)$$

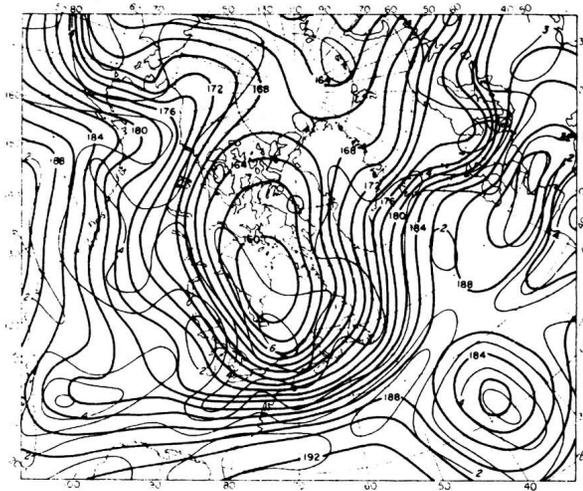
1. Compute Jacobian
2. Step forward (Leapfrog scheme)
3. Solve Poisson equation for ψ (Fourier expansion)
4. Go to (1).
 - Timestep : $\Delta t = 1$ hour (2 and 3 hours also tried)
 - Gridstep : $\Delta x = 750$ km (approximately)
 - Gridsize : $18 \times 15 = 270$ points
 - Elapsed time for 24 hour forecast: About 24 hours.

Forecast involved **punching about 25,000 cards**. Most of the elapsed time was spent handling these.

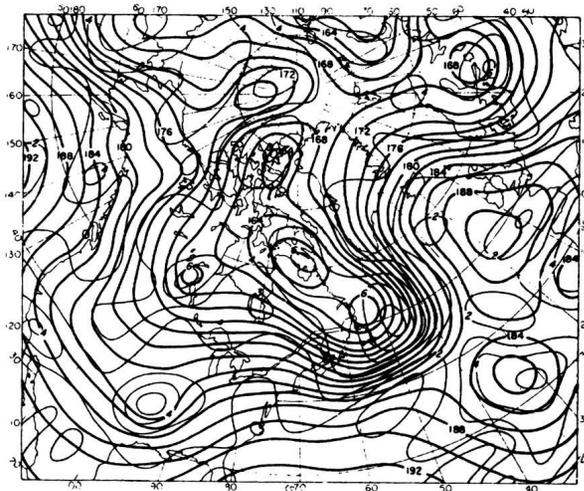
ENIAC Algorithm



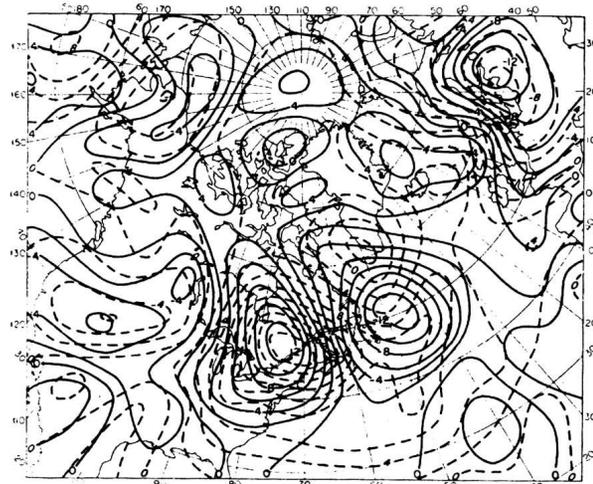
ENIAC: First Computer Forecast



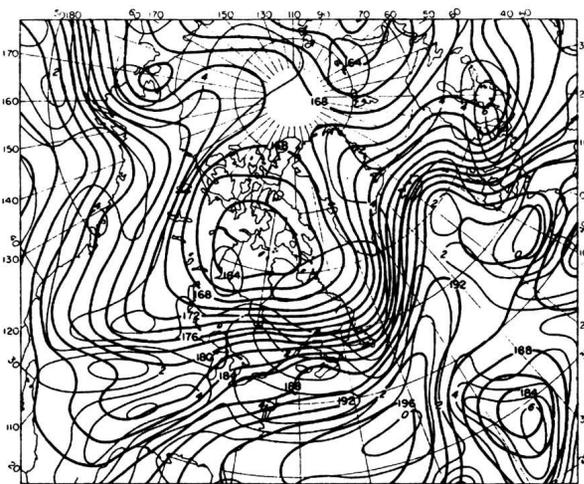
(A)



(B)



(C)



(D)

Richardson's reaction

- *“Allow me to congratulate you and your collaborators on the remarkable progress which has been made in Princeton.*
- *“This is . . . **an enormous scientific advance** on the single, and quite wrong, result in which Richardson (1922) ended.*

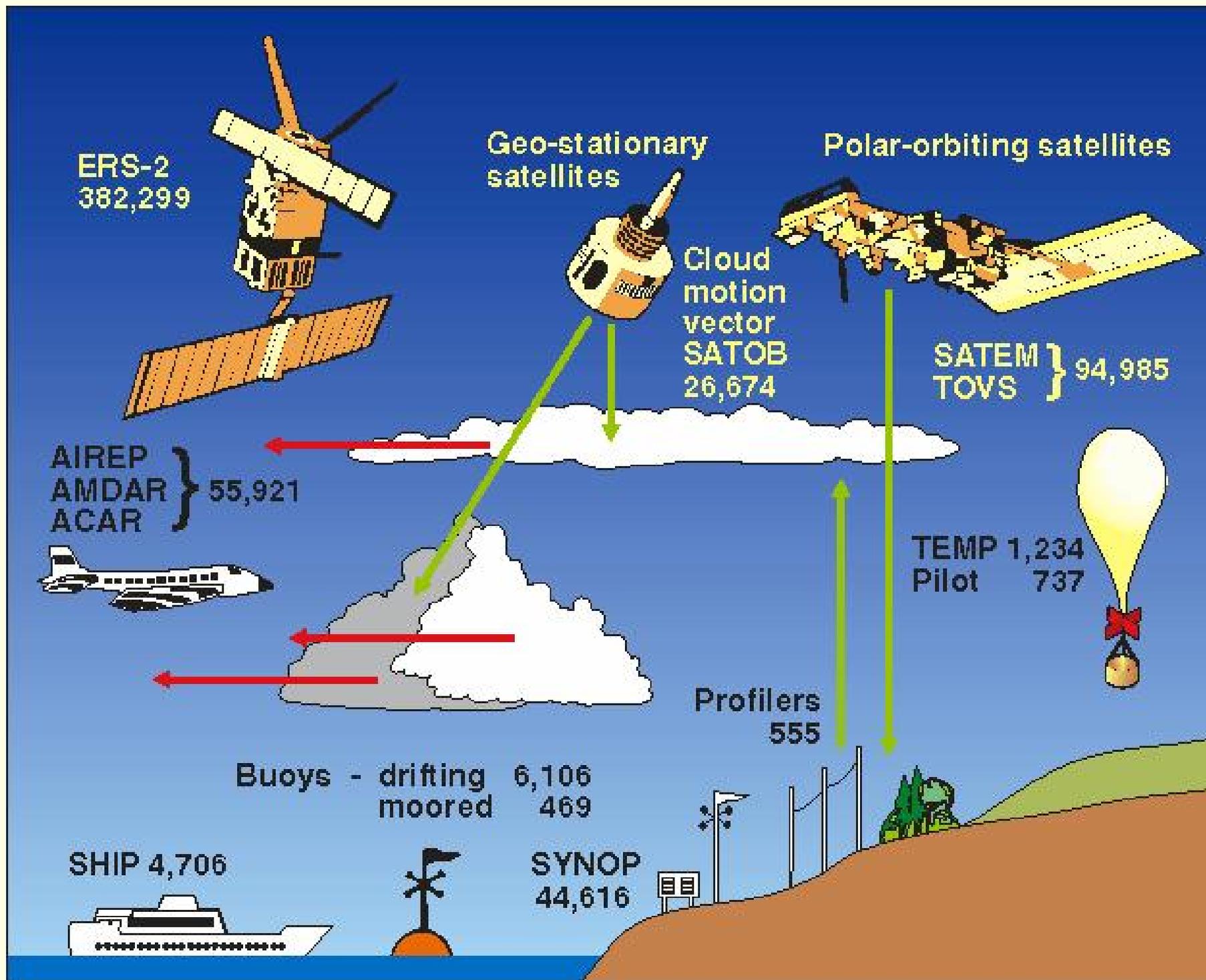
NWP Operations

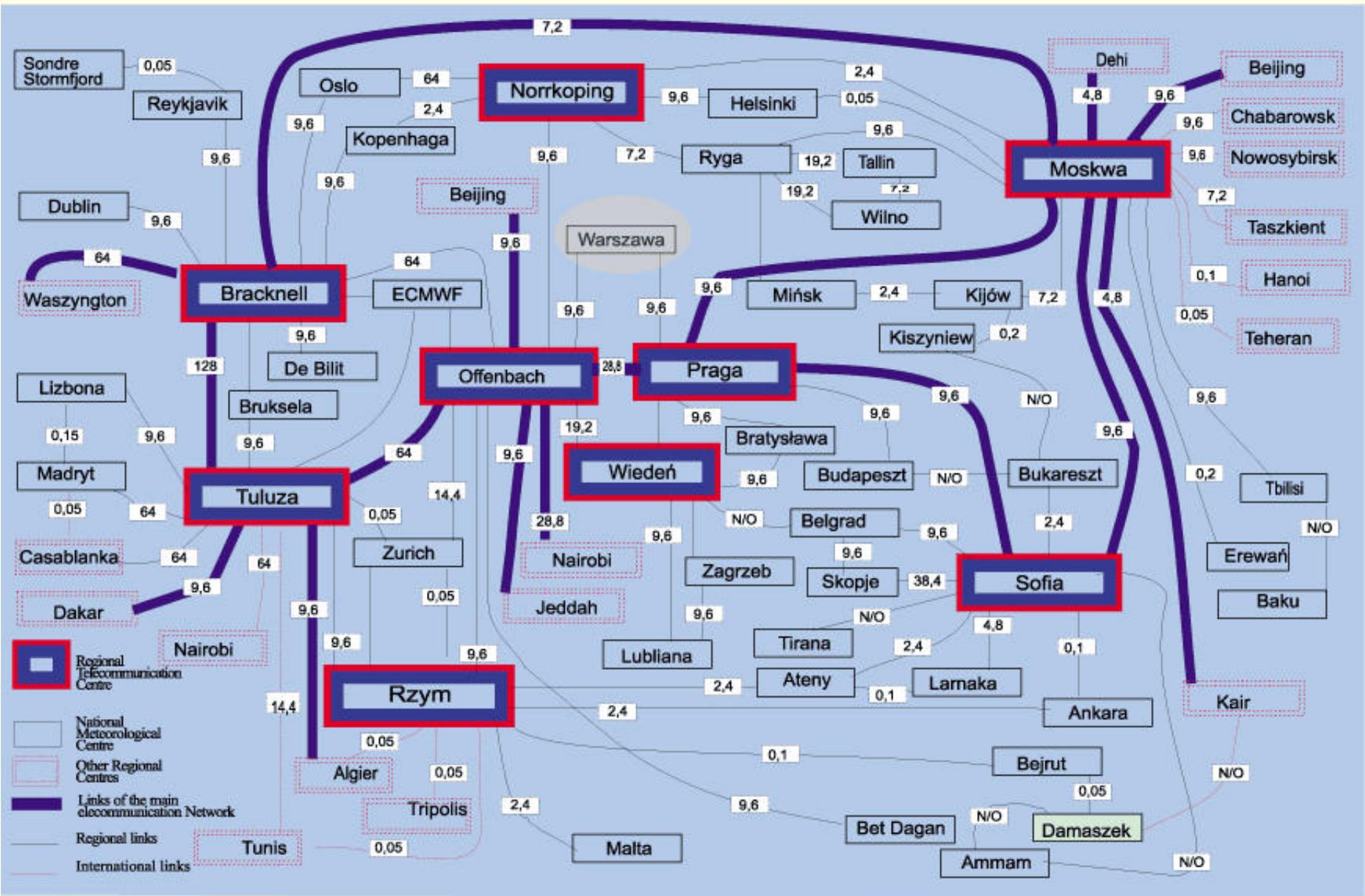
The Joint Numerical Weather Prediction (JNWP) Unit was established on July 1, 1954:

- *Air Weather Service of US Air Force*
- *The US Weather Bureau*
- *The Naval Weather Service.*

Operational numerical forecasting began on 15 May, 1955, using a three-level quasi-geostrophic model.

Computer
Forecasting
Today





Global Telecommunication System of the World Meteorological Organization
 (transmission in kilobits per second)

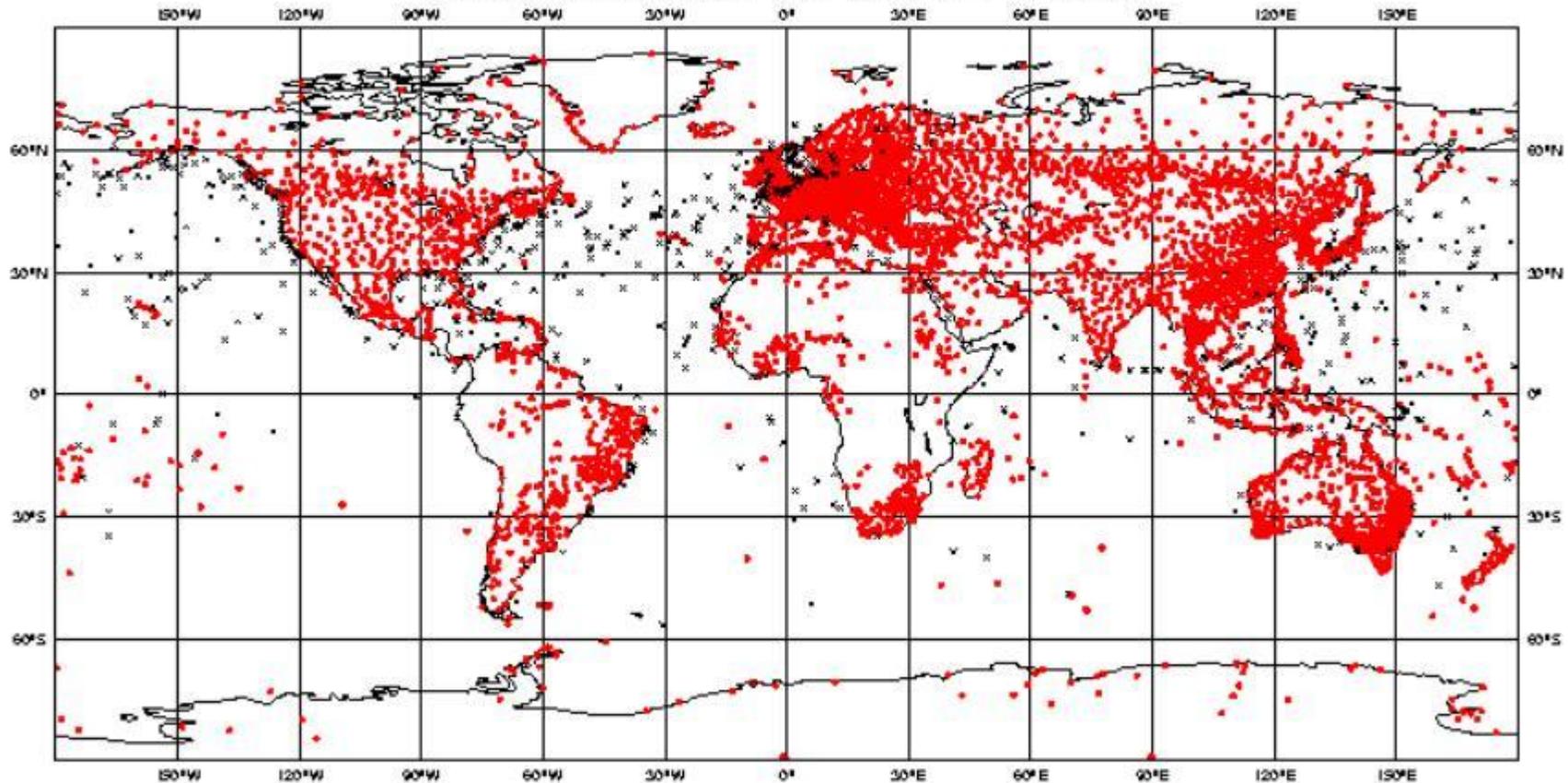


ECMWF Data Coverage - SYNOP/SHIP

28/FEB/1999; 00 UTC

Total number of obs = 12688

- 11417 SYNOP
- 1271 SHIP

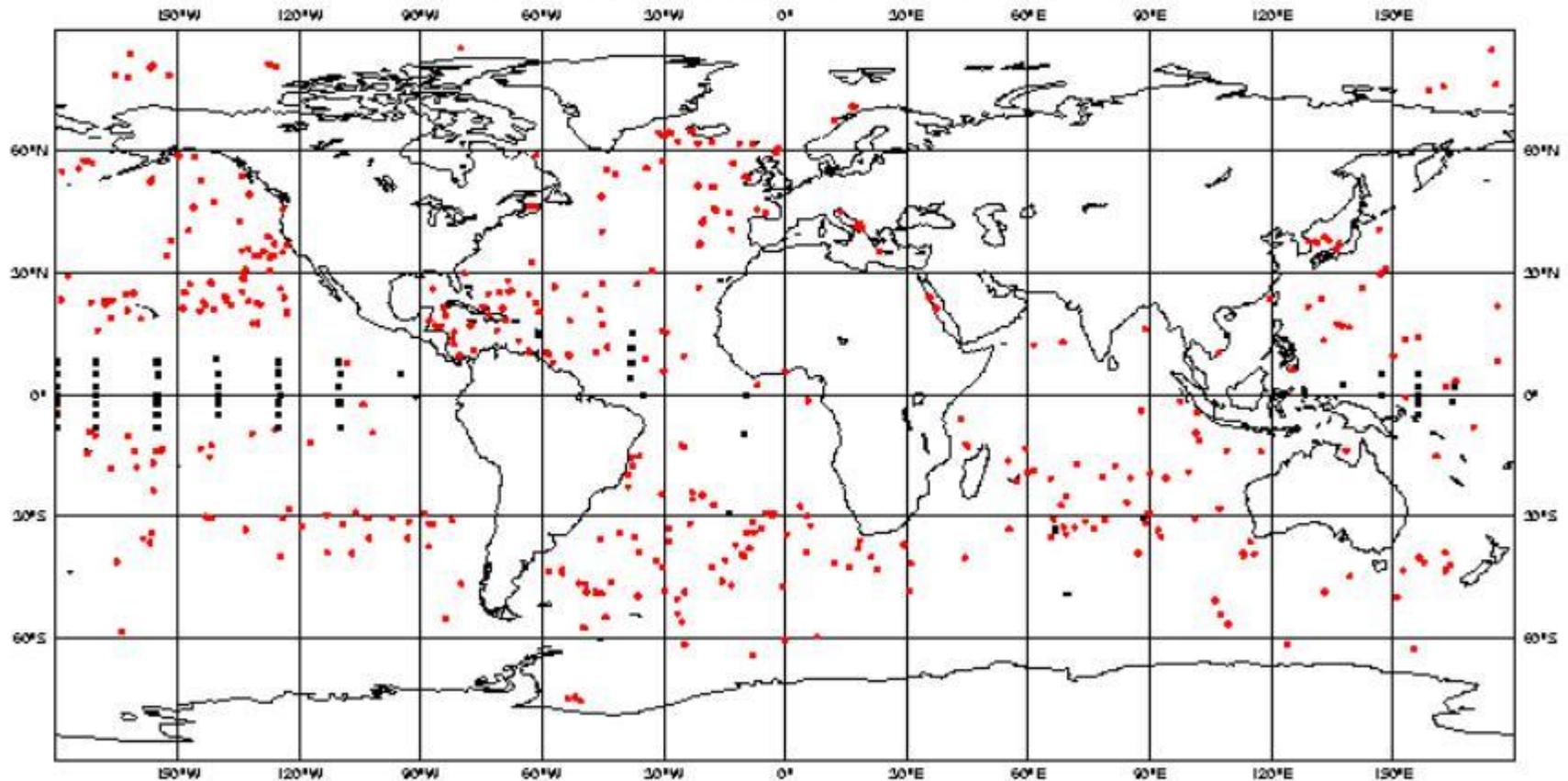


ECMWF Data Coverage - BUOY

28/FEB/1999; 00 UTC

Total number of obs = 1568

- 1468 DRIFTER
- 100 MOORED

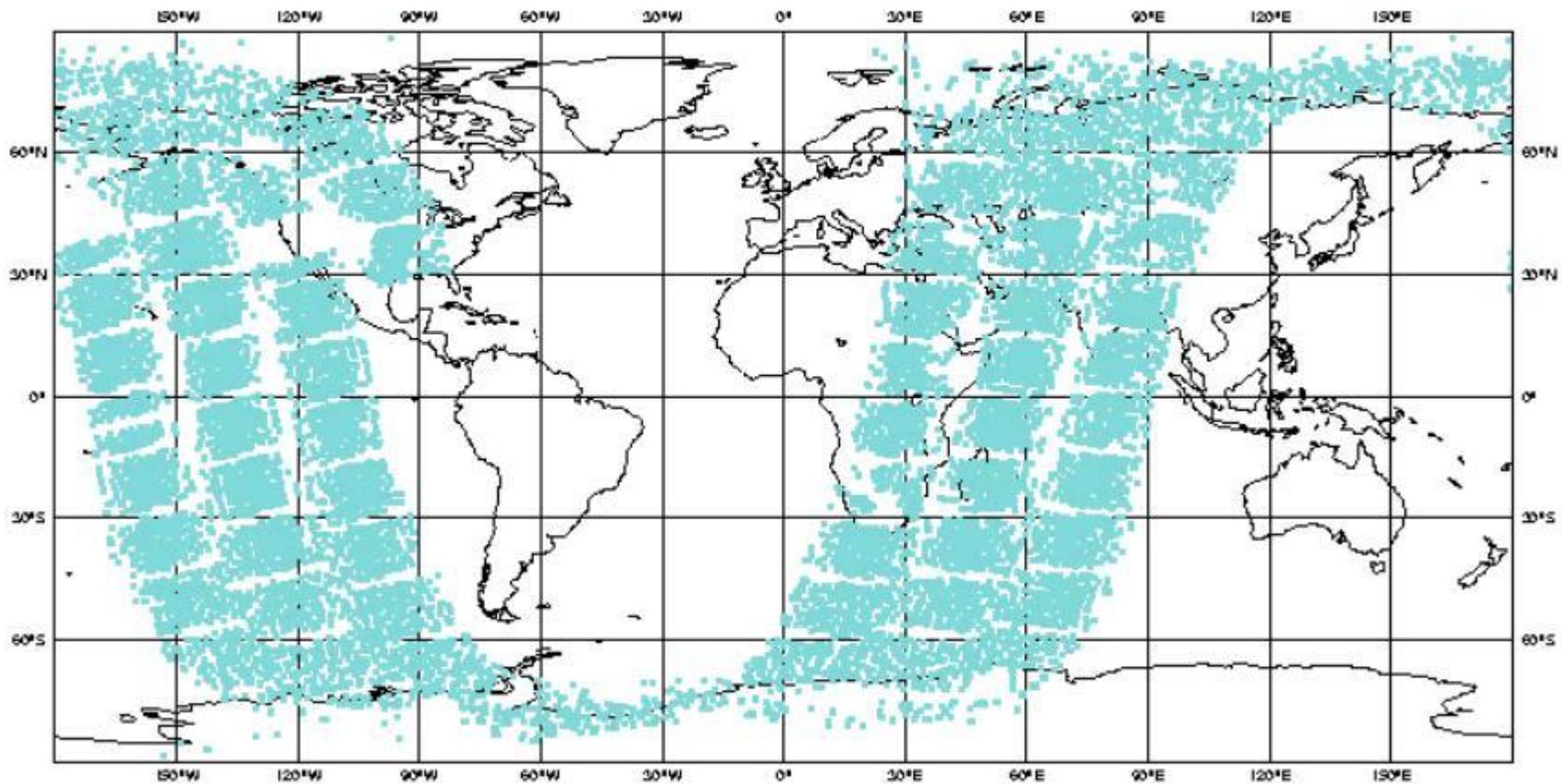


ECMWF Data Coverage - TOVS (120km)

28/FEB/1999; 00 UTC

Total number of obs = 11005

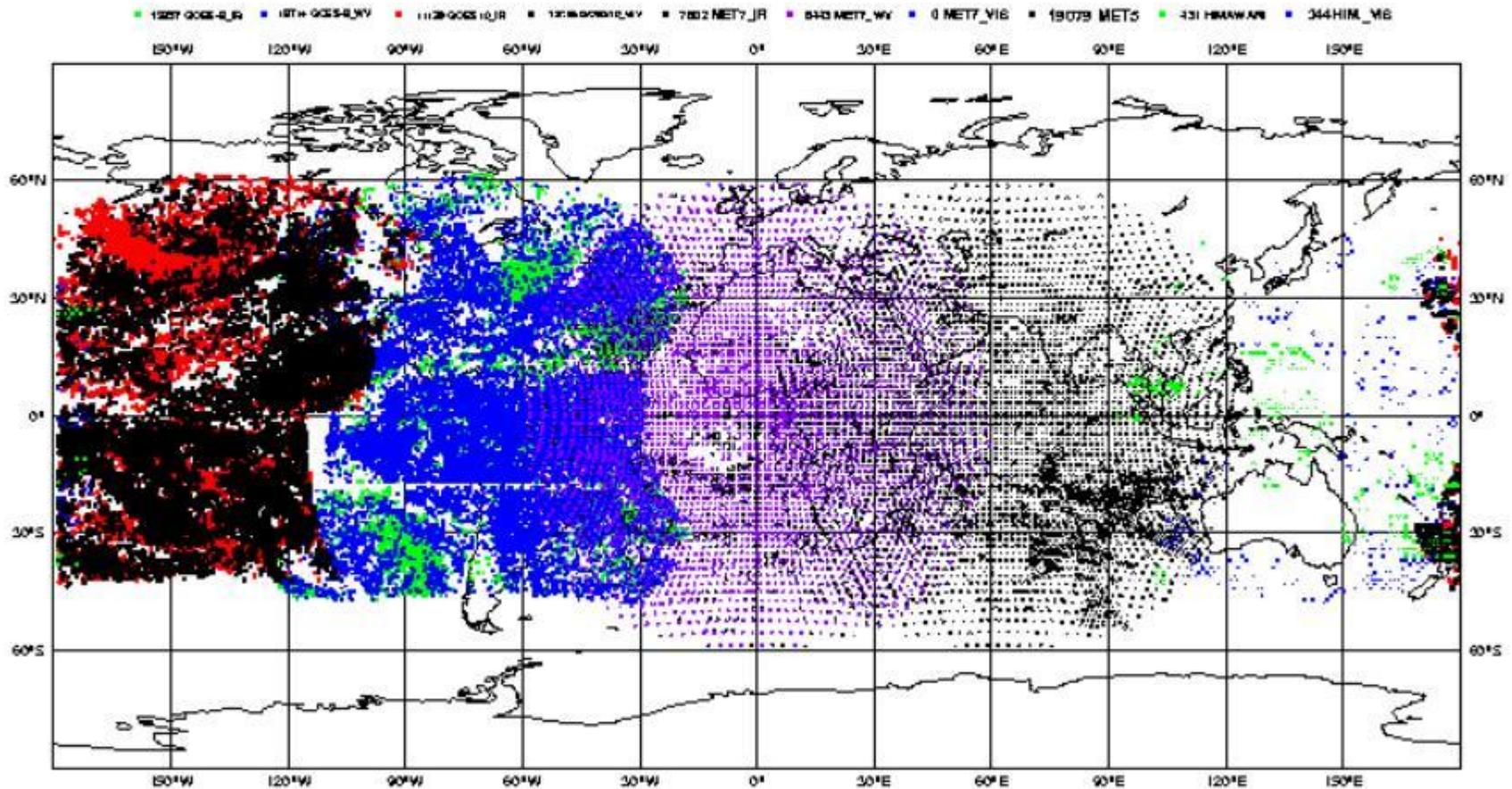
0 NDAA11
11005 NOAA14



ECMWF Data Coverage - SATOB

28/FEB/1999; 00 UTC

Total number of obs = 91405



Met Éireann Headquarters



MET ÉIREANN - The Irish Meteorological Service - Netscape



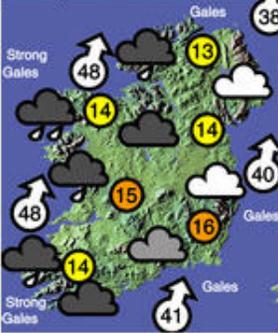
MET ÉIREANN

The Irish Meteorological Service

04 November 2003

04 November 2003 - updated at 11:32hrs

Today



Weather in Brief

Mild. Windy. Gusts to 50 or 60 mph locally (mainly in West and Northwest). Generally cloudy. Rain in West and Northwest - turning heavy at times, but may ease off or die out overnight. Mostly or completely dry elsewhere.

MET ÉIREANN HEADQUARTERS, Glasnevin Hill, Dublin 9, Ireland
T: +353 1 8064200 F: +353 1 8064247

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 Please note that the times indicated in forecasts and reports may be local or UTC.

QUICKLINKS

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Celsius / Fahrenheit Converter

Enter a number in a field then click the button.

C: F:

[FORECASTS](#)
[RECENT WEATHER](#)
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[ABOUT US](#)
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[AVIATION](#)
[HOME](#)

The Met Éireann web site: www.met.ie



- *HIRLAM is a state-of-the-art prediction model for short-range forecasting*
- *It is based on the Primitive Equations*
- *It has a comprehensive parameterization package for physical processes*
- *HIRLAM is the basis for short-range forecasting operations at Met Éireann.*

Extensive model documentation is available at <http://hirlam.knmi.nl/>

The HIRLAM Project

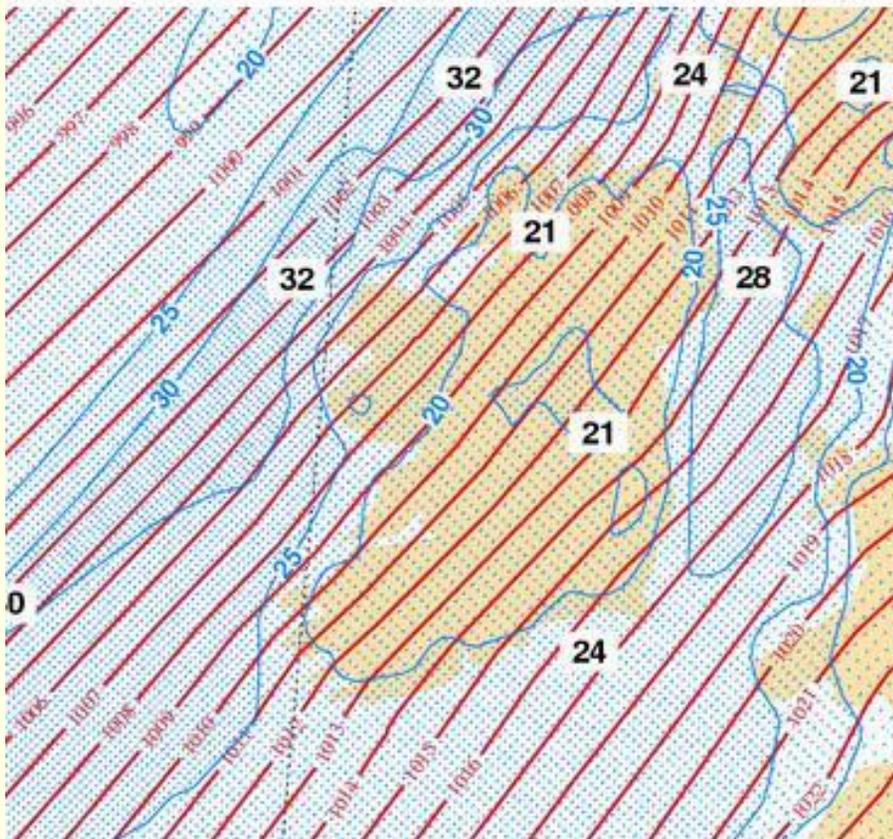
HiRLAM stands for **H**igh **R**esolution **L**imited **A**rea **M**odel.

The members of the HiRLAM Project are:

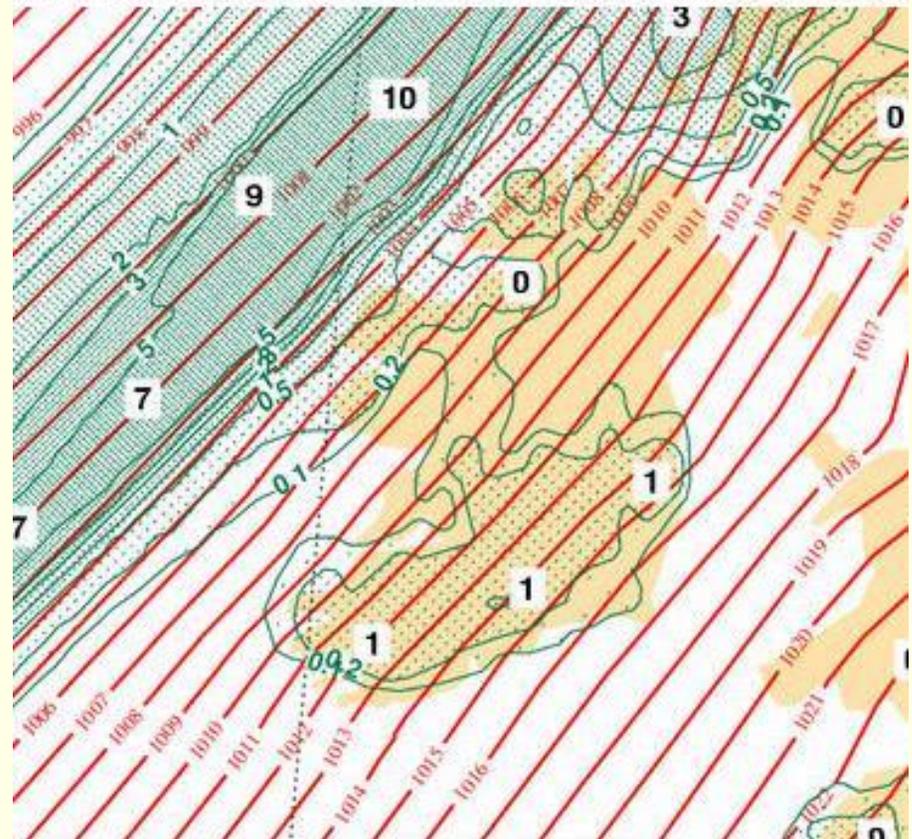
- Danish Meteorological Institute (DMI)
- Finnish Meteorological Institute (FMI)
- Icelandic Meteorological Office (VI)
- Met Éireann, Ireland (IMS)
- Royal Netherlands Meteorological Institute (KNMI)
- The Norwegian Meteorological Institute (met.no)
- Spanish Meteorological Institute (INM)
- Swedish Meteorological and Hydrological Institute

Hourly HiRLAM Forecast Charts

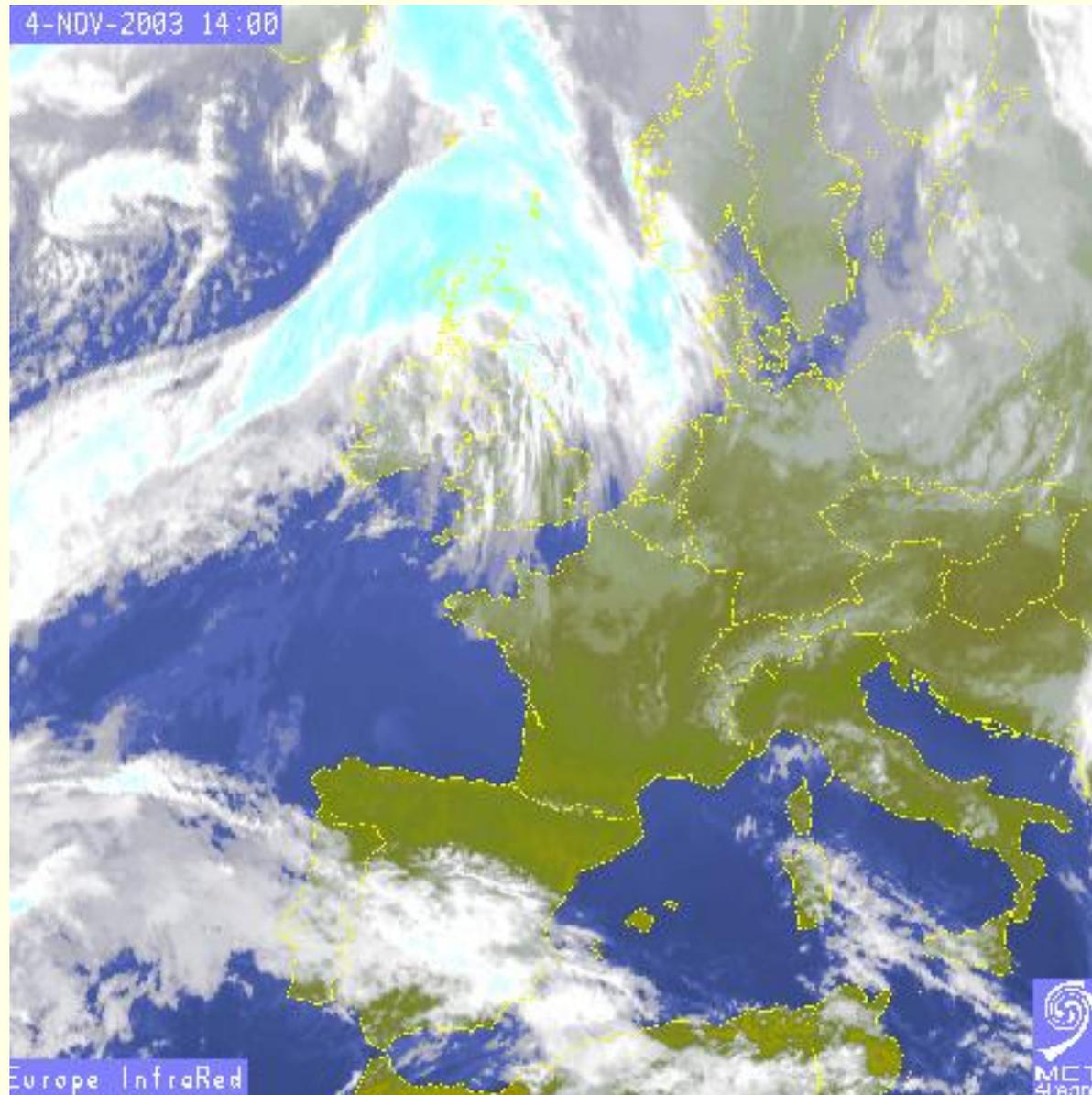
3 HOUR MSL PRESSURE/WINDSPEED (KTS) FORECAST FOR: 16 UTC 4 NOV 2003



3 HOUR MSL PRESSURE/ACCUMULATED RAINFALL (MM) FORECAST FOR: 16 UTC 4 NOV 2003



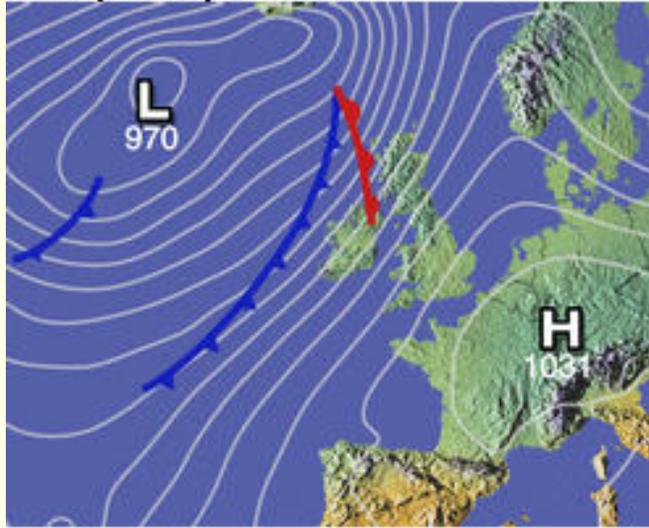
Satellite Imagery



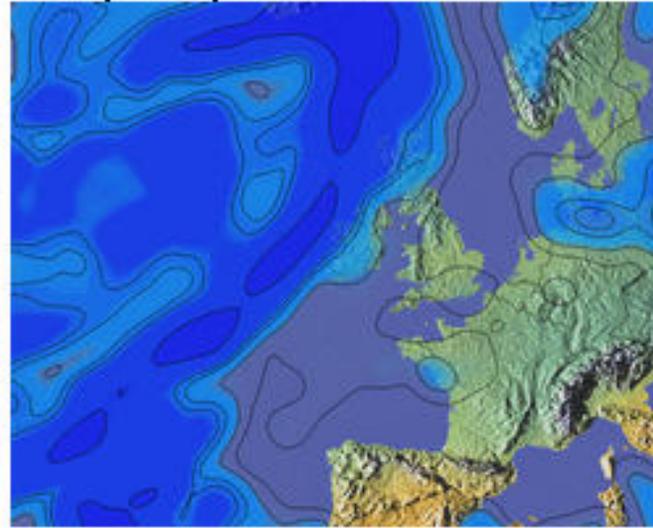
Atlantic Analysis Charts

Today : 1200, 04 November 2003

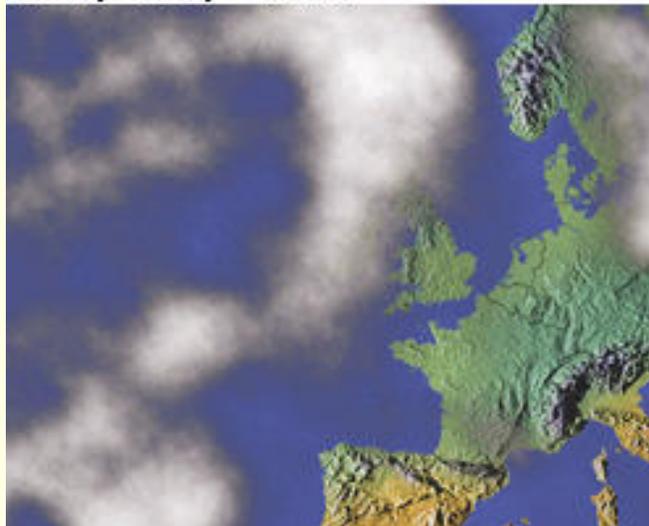
Midday Today - Isobars



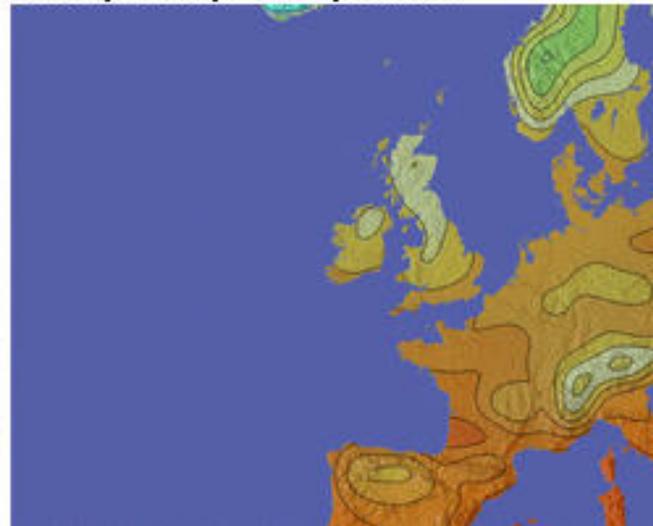
Midday Today - Rainfall



Midday Today - Clouds



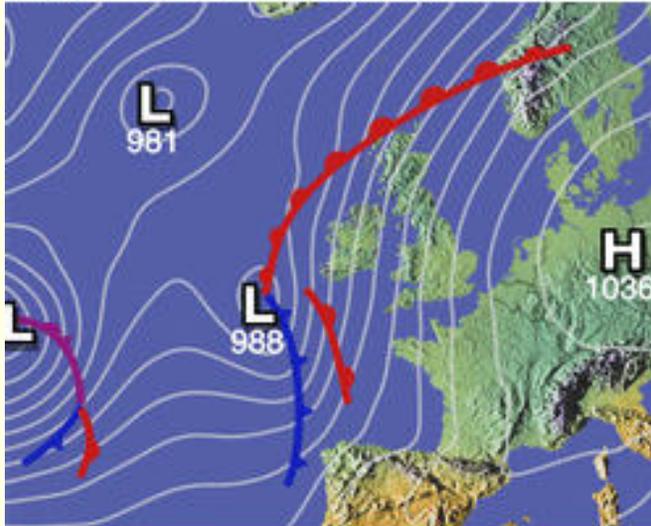
Midday Today - Temperature



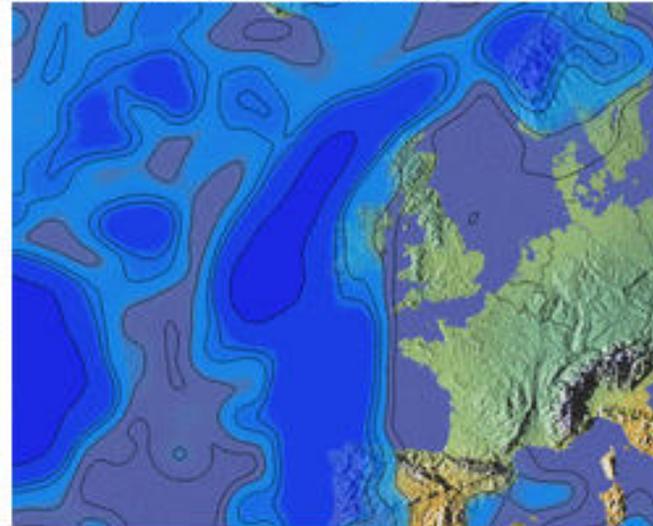
Atlantic Forecast Charts

📍 Tomorrow: 1200, 05 November 2003

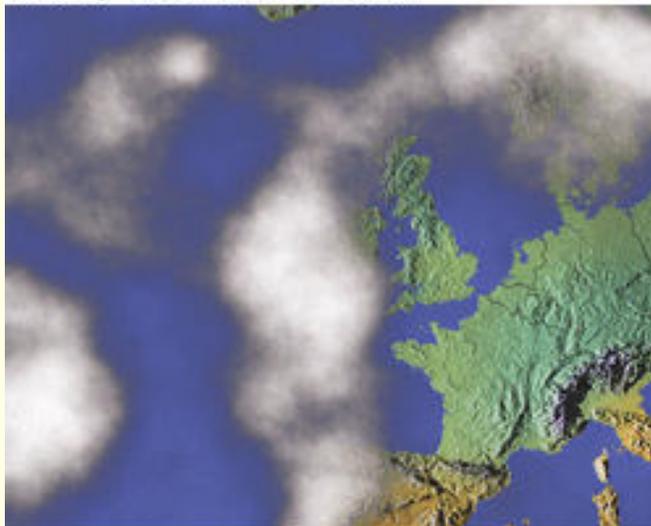
Midday Tomorrow - Isobars



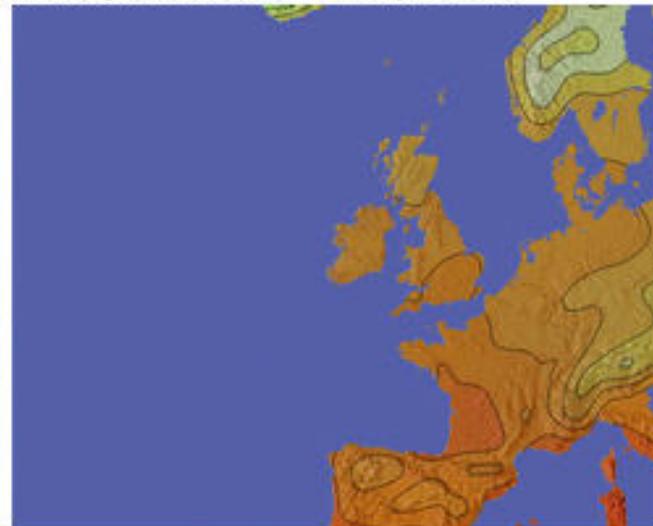
Midday Tomorrow - Rainfall



Midday Tomorrow - Clouds



Midday Tomorrow - Temperature



ECMWF



European Centre for Medium range Forecasts. Reading Headquarters.

ECMWF: World leader in NWP

Established in 1975, ECMWF is situated in Reading, Berkshire, with a staff of 216.

The Centre is renowned worldwide as providing the most accurate medium-range global weather forecasts to ten days and seasonal forecasts to six months.

Its products are provided to the European National Weather Services, as a complement to the national short-range and climatological activities.

Eighteen Member States, including Ireland, support ECMWF.

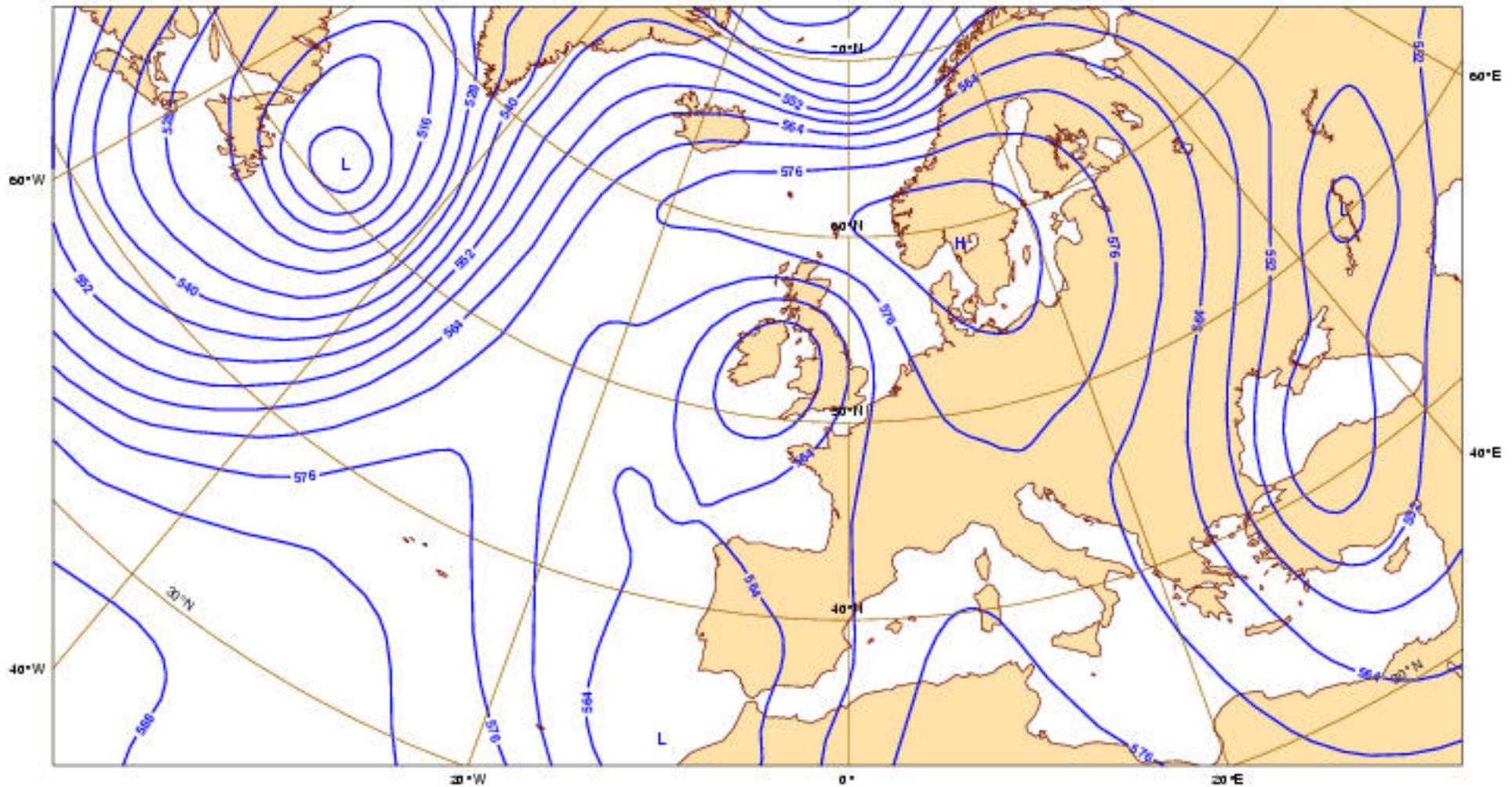
PRESS RELEASE (2 Dec., 2003)

New Director of ECMWF

The Council of the European Centre for Medium-Range Weather Forecasts has appointed **Mr. Dominique Marbouty** as Director of ECMWF from 18 June 2004.

Seven-day Forecast from ECMWF

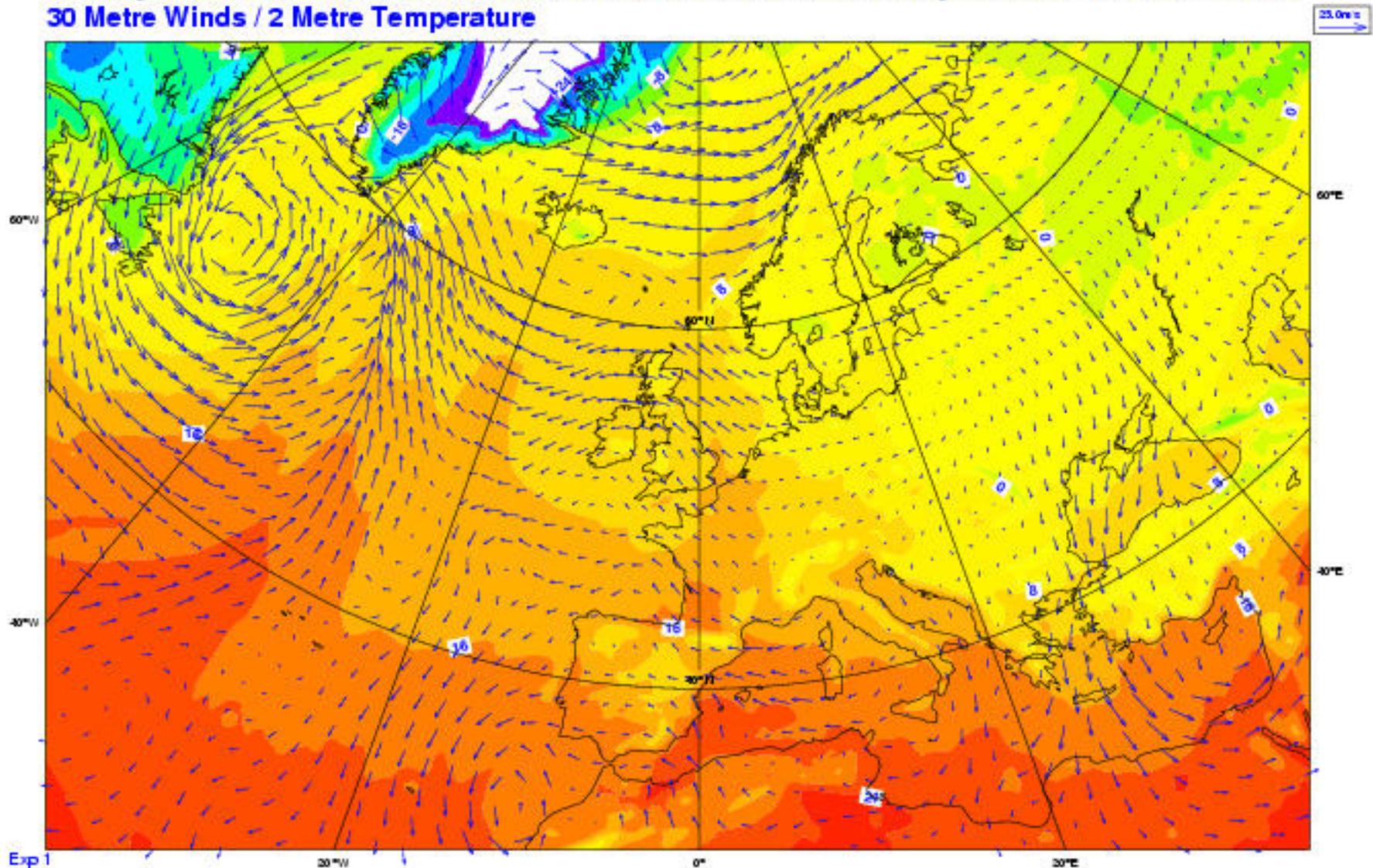
Monday 3 November 2003 12UTC ECMWF Forecast t+168 VT: Monday 10 November 2003 12UTC
500 hPa Height



500 hPa Height Forecast

Seven-day Forecast from ECMWF

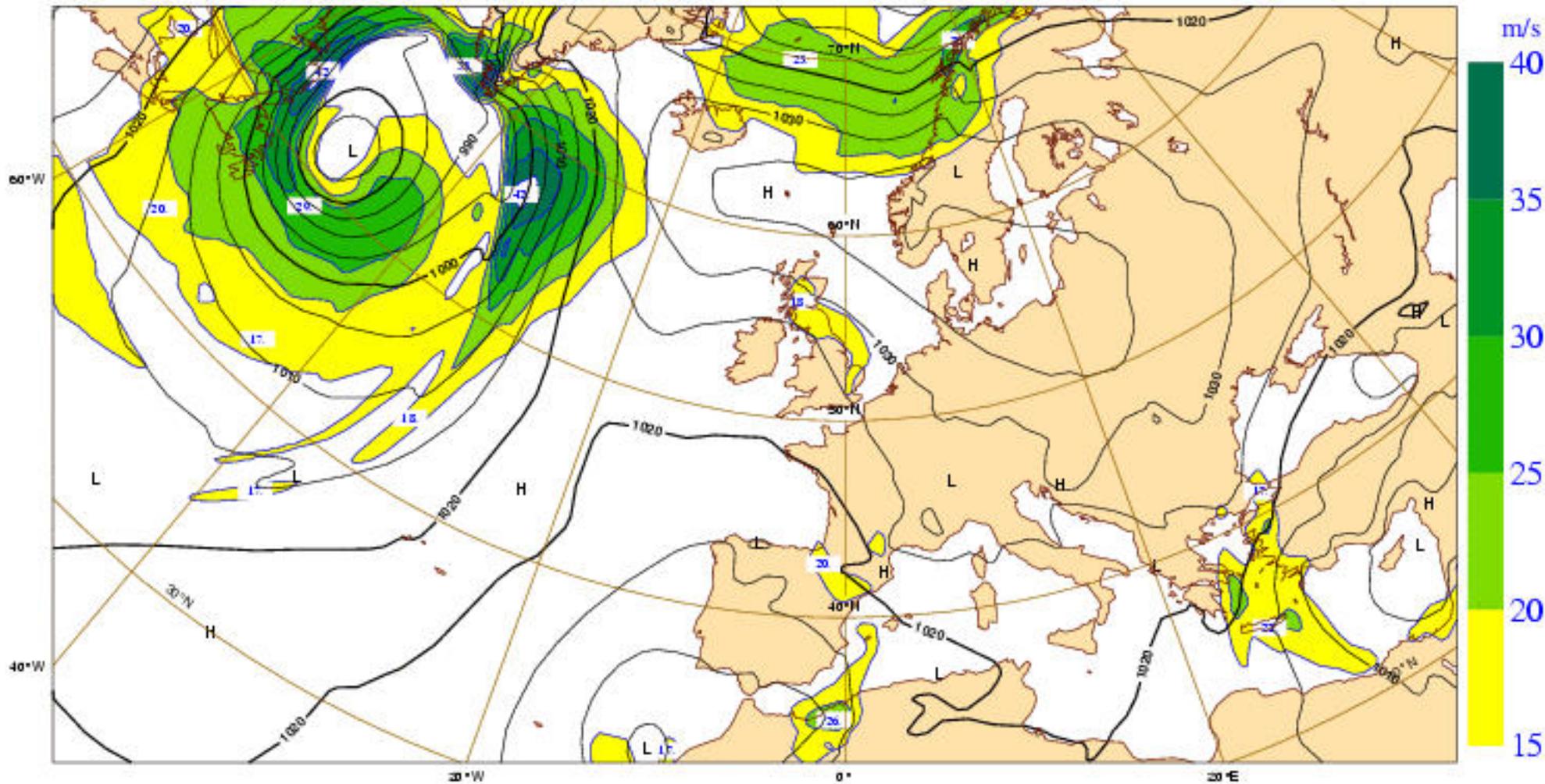
Monday 3 November 2003 12UTC ECMWF Forecast t+168 VT: Monday 10 November 2003 12UTC
30 Metre Winds / 2 Metre Temperature



2m Temperature and 30m Wind Forecast

Seven-day Forecast from ECMWF

Monday 3 November 2003 12UTC ECMWF Forecast +168 VT: Monday 10 November 2003 12UTC 850hPa u-velocity/ mean sea level pressure
SURFACE: MSL Pressure / 850-hPa wind speed



MSL Pressure and 850hPa Wind Forecast

Atmospheric Predictability

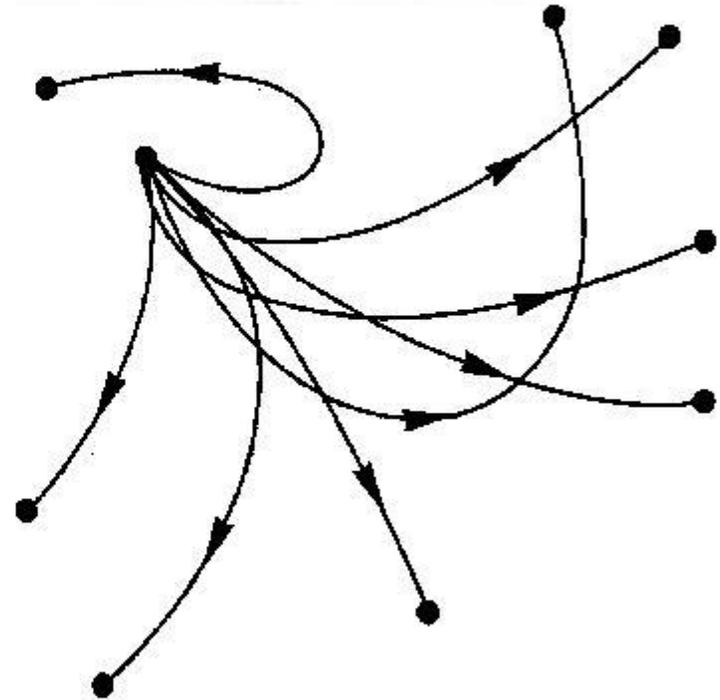
and

Ensemble Forecasting

Variation in Predictability



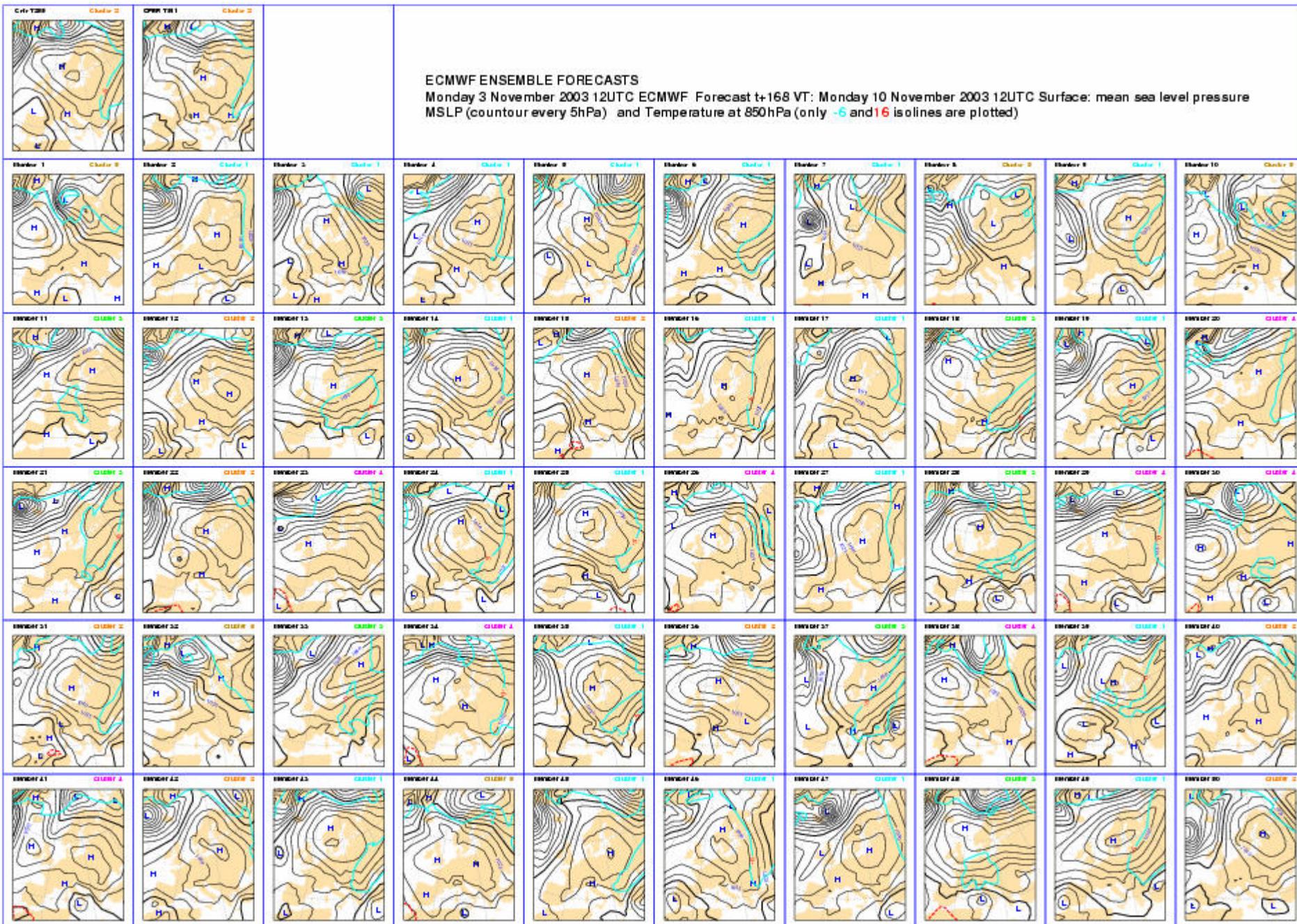
Highly Predictable



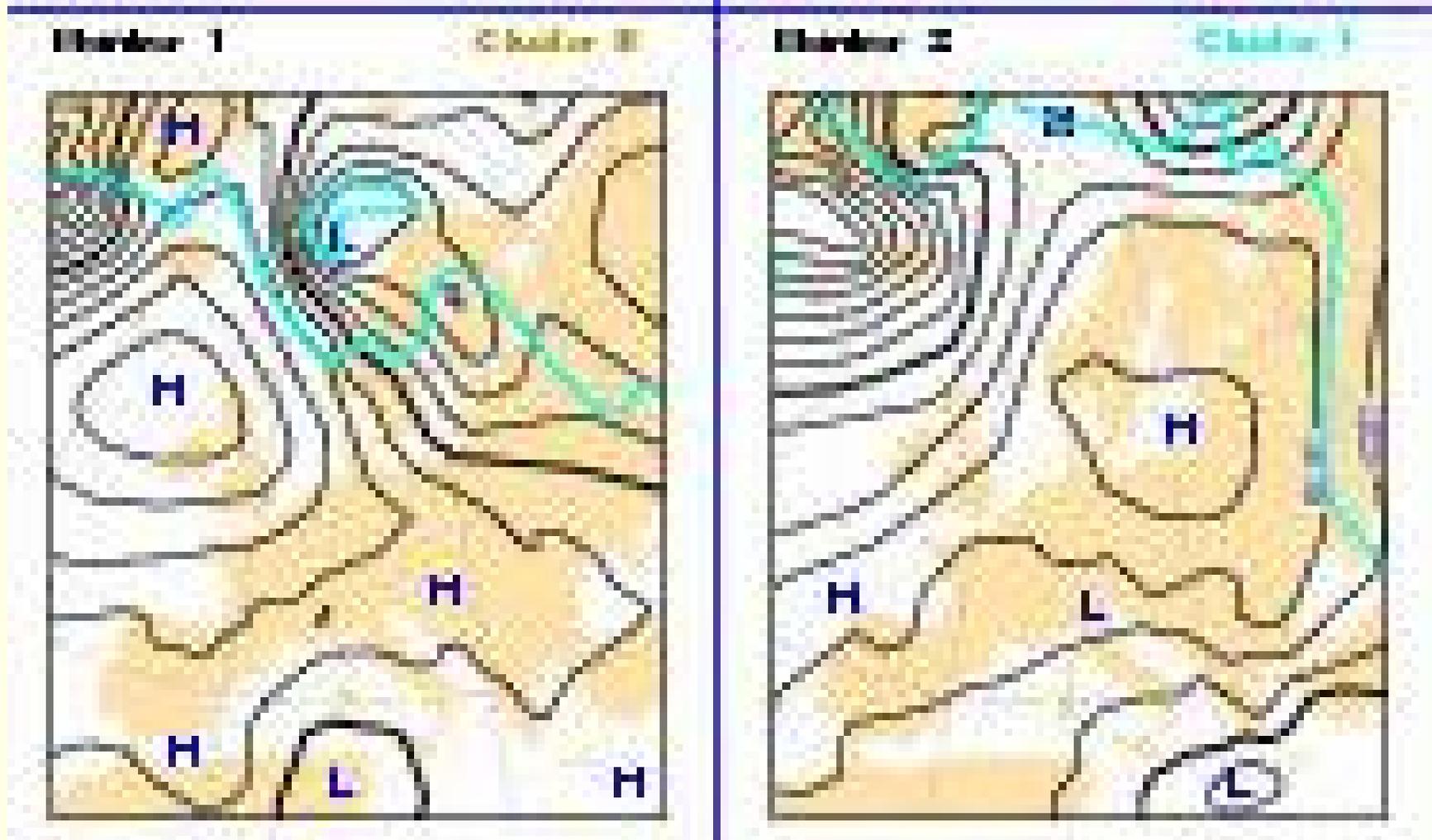
Highly Unpredictable

Laminar and Turbulent Flow





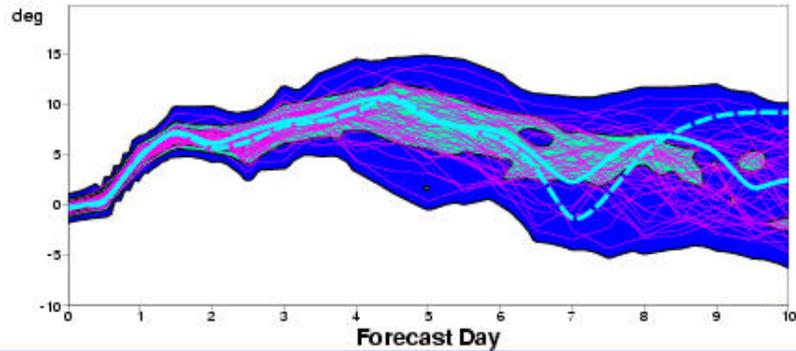
Ensemble Forecast for Today



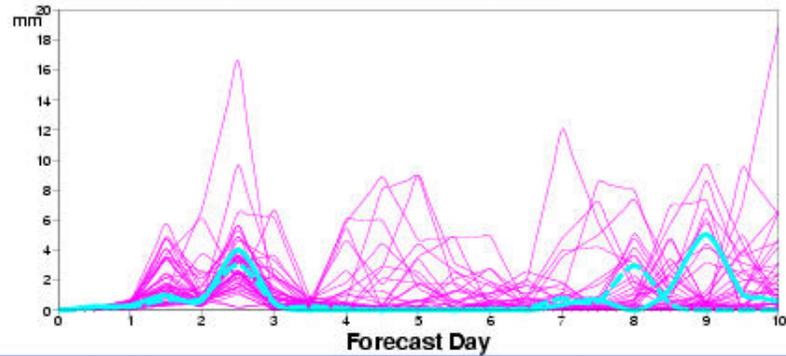
ECMWF ENSEMBLE FORECASTS FOR: IRELAND
 DATE: 20031103 DUBLIN LAT: 53.4 LONG: -6.3

■ 0.5 - 10 %
 ■ 10 - 30 %
 ■ 30 - 50 %
 ■ 50 - 100 %
 --- Oper --- T255 --- EMem

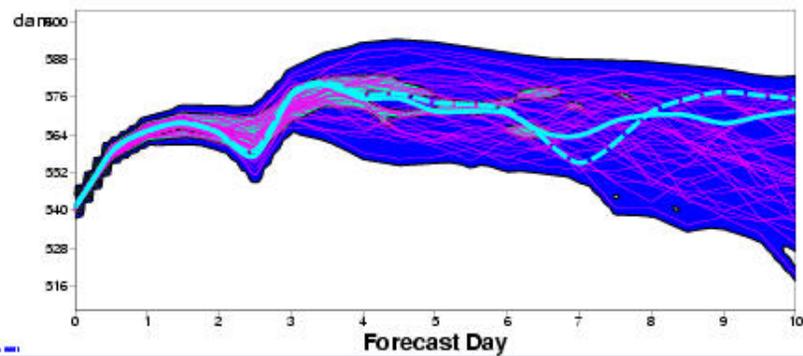
TEMPERATURE 850hPa - Probability for 1.0 deg intervals Range: 30deg



Ensemble members of TOTAL PRECIPITATION - Accum. rate mm/12h



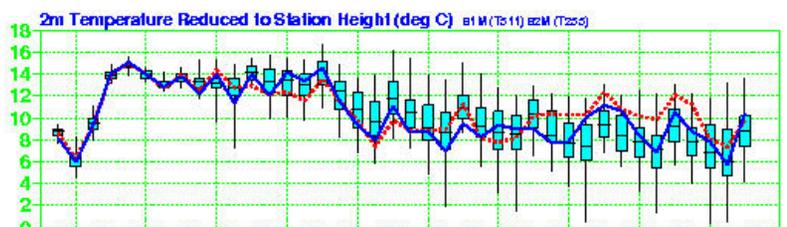
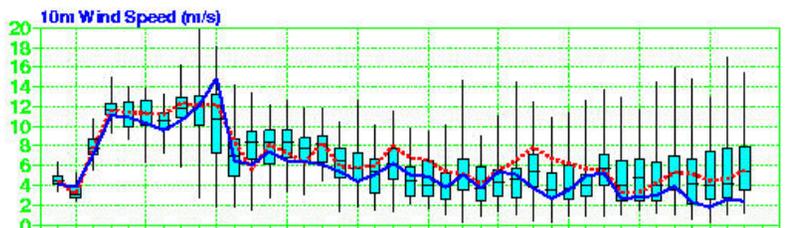
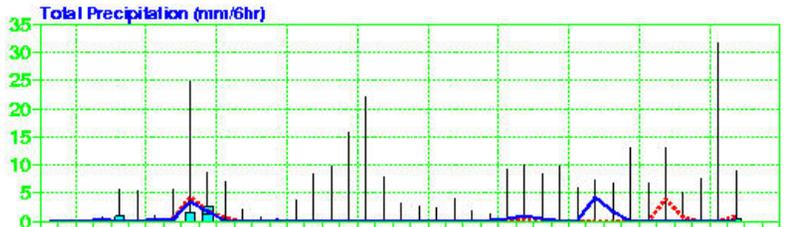
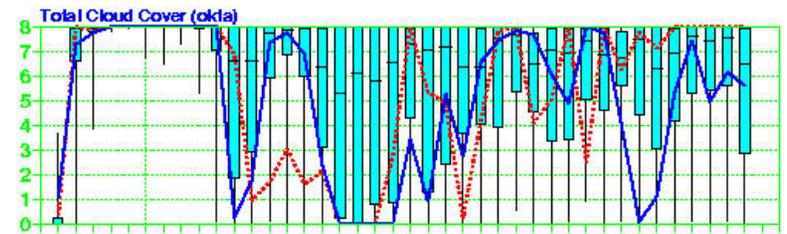
GEDPOTENTIAL 500hPa - Probability for 2.5 dam intervals Range: 96dam



EPS Meteogram

Dublin 53.7° N 6.7° W

Deterministic Forecasts and EPS Distribution 3 November 2003 12 UTC



TUE 4 WED 5 THU 6 FRI 7 SAT 8 SUN 9 MON 10 TUE 11 WED 12 THU 13
 NOVEMBER 2003

■ max
 ■ 75%
 ■ median
 ■ 25%
 ■ min
 --- T255 CTRL --- T1511 QFS



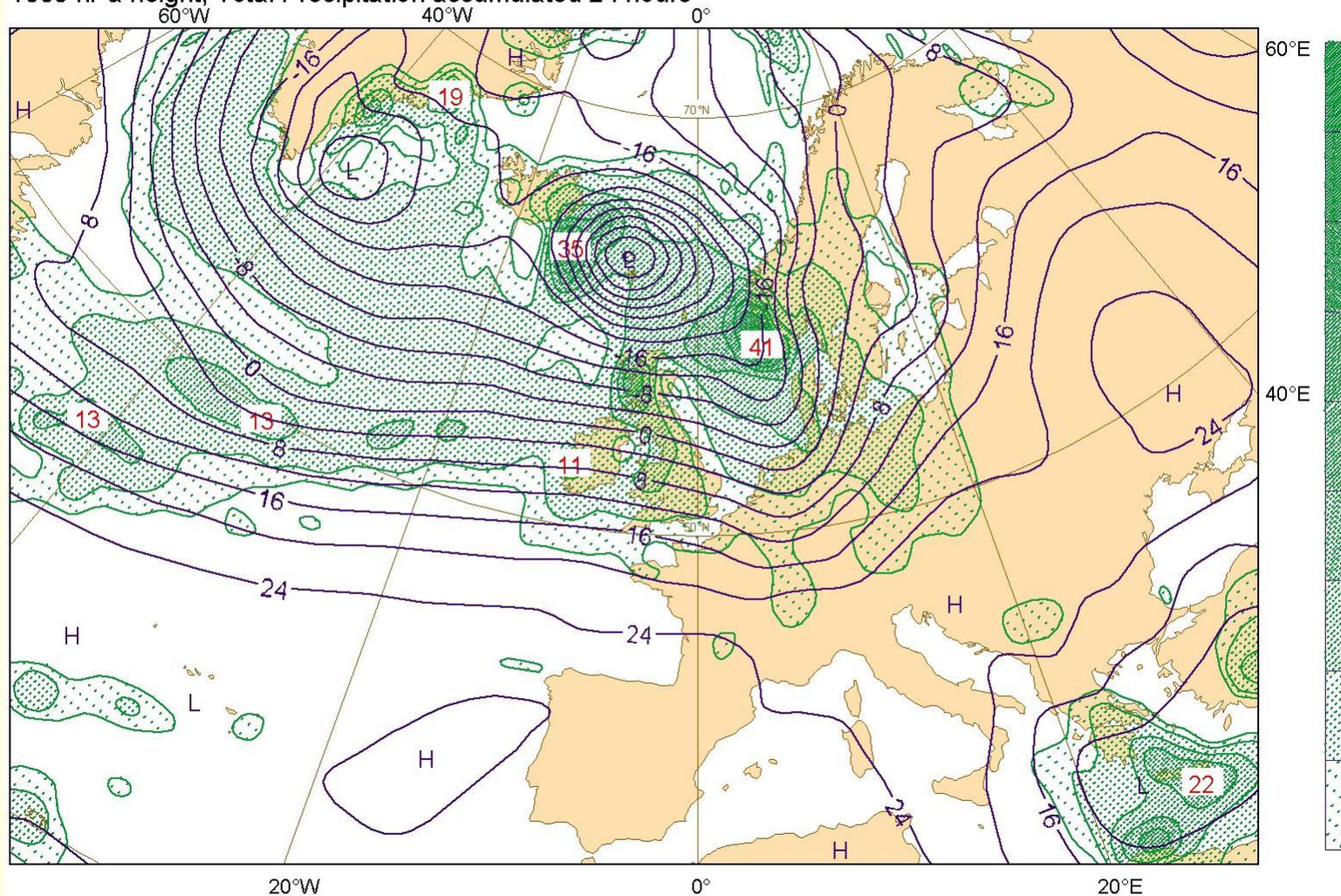
Deterministic

Forecast

Accuracy

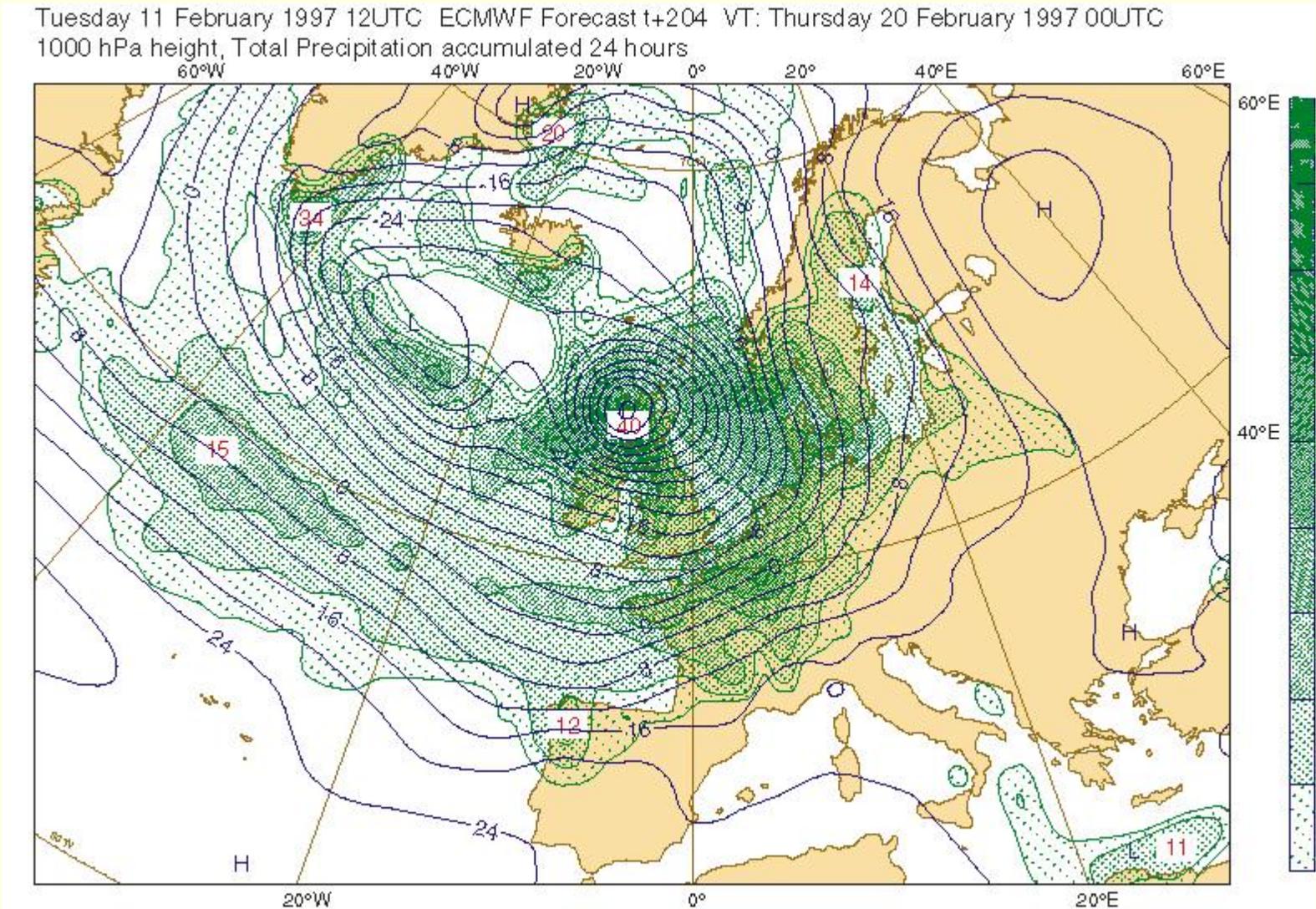
Objective Analysis of Pressure

ECMWF Analysis VT: Thursday 20 February 1997 00UTC
1000 hPa height, Total Precipitation accumulated 24 hours



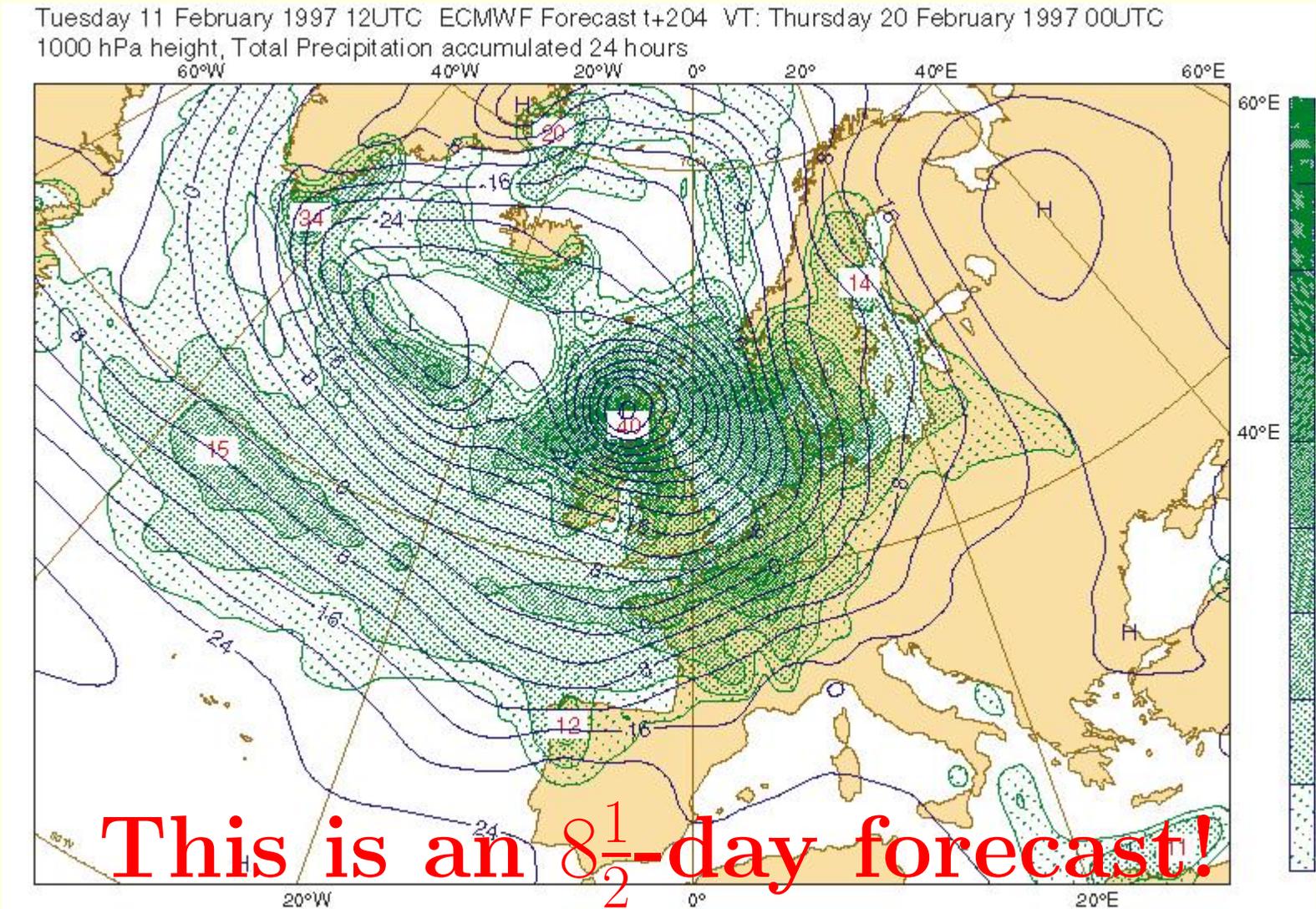
Analysis of 1000hPa height and 24hr precipitation.

Prediction of Surface Conditions



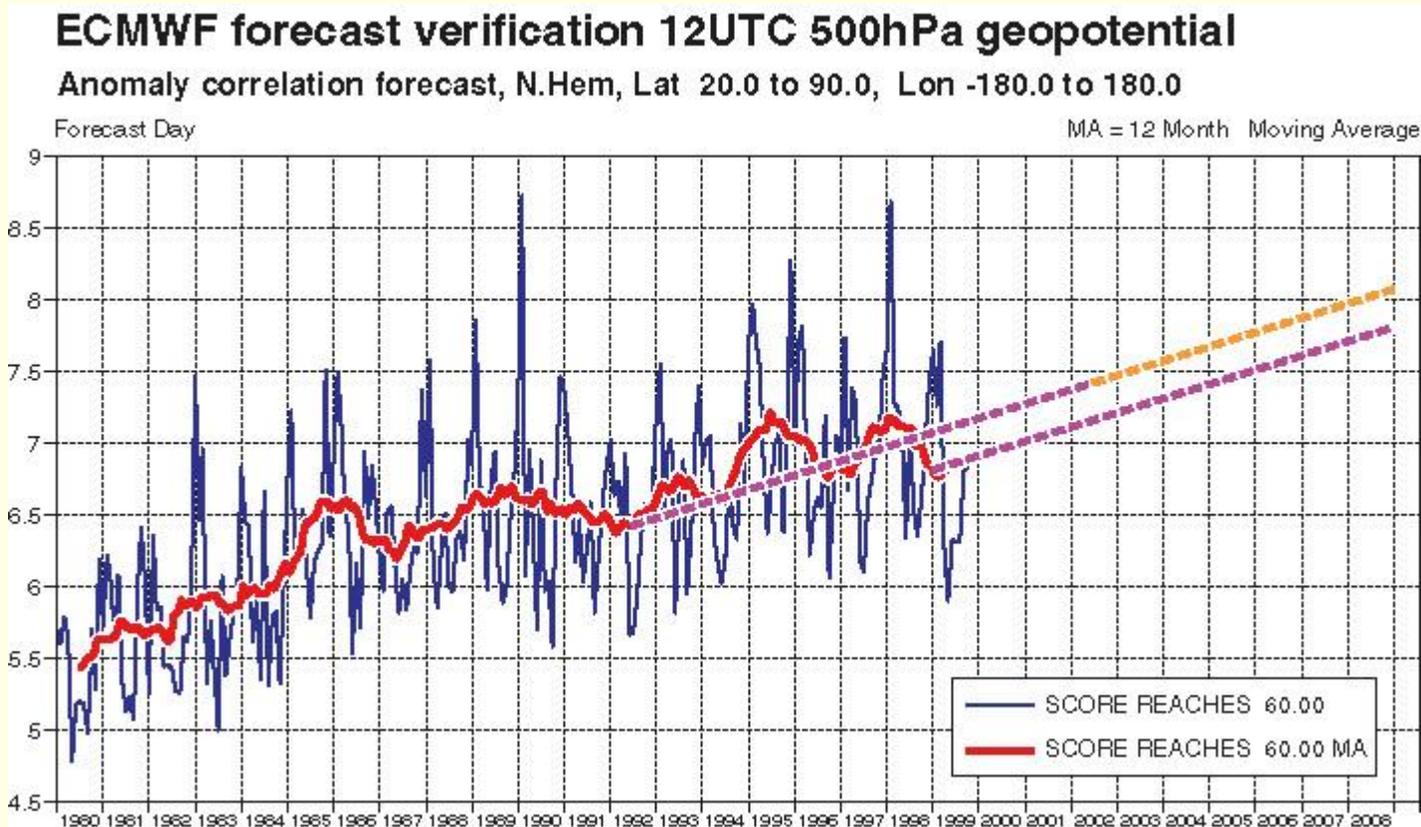
Forecast of 1000hPa height and 24hr precipitation.

Prediction of Surface Conditions



Forecast of 1000hPa height and 24hr precipitation.

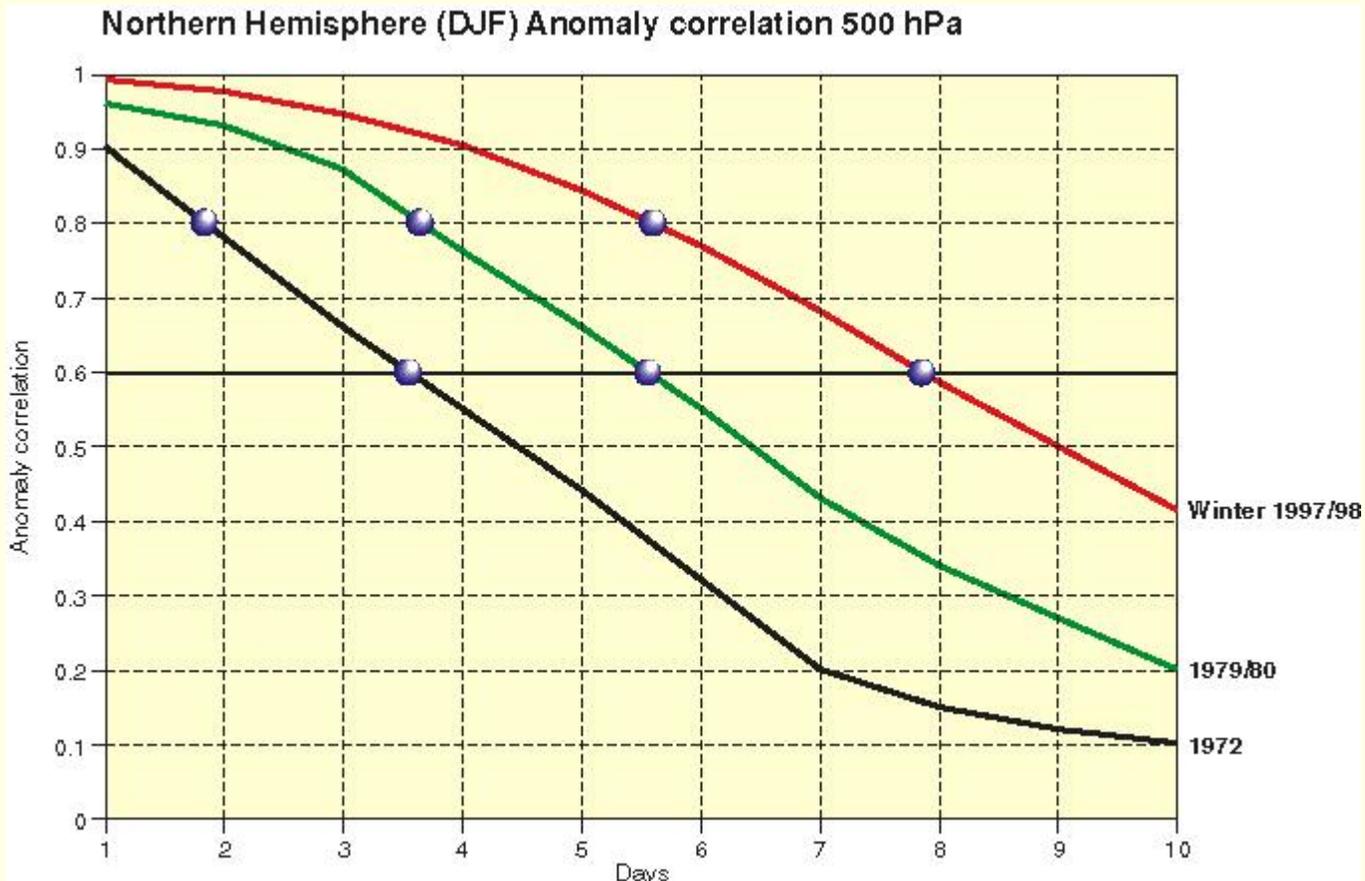
Objective Measure of Skill



Skill of 500 mb geopotential height. Forecast day when
Anomaly Correlation falls to 0.6

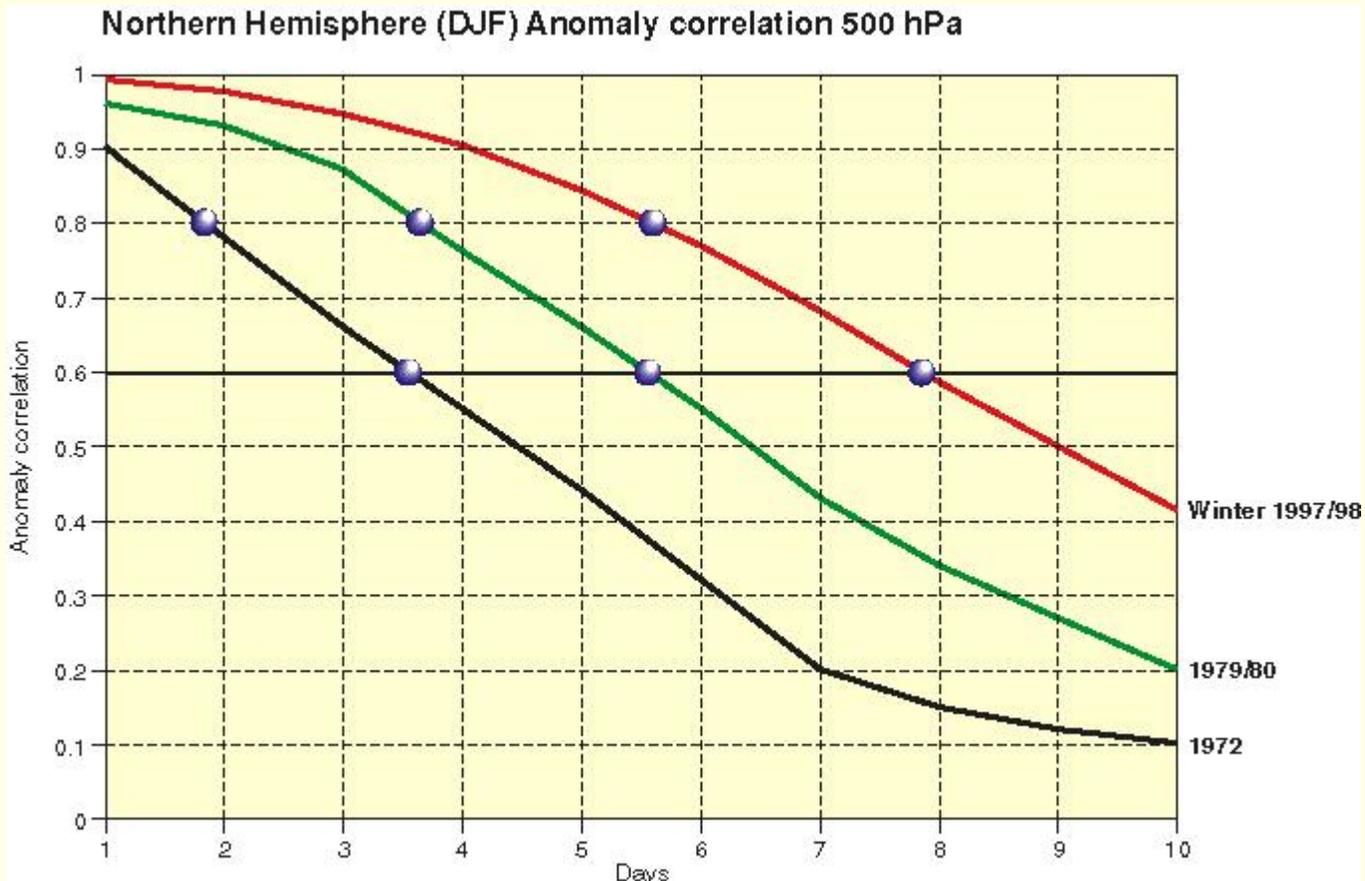
This is a measure of the **useful forecast range**.

Objective Measure of Skill



Comparative skill of 500 mb forecasts.

Objective Measure of Skill



Comparative skill of 500 mb forecasts.
The **six-day** forecasts now are as good as the **two-day** forecasts were in 1972.

Current Status of NWP

- *Much remains to be done in improving the accuracy of short range forecasts.*
- *We need more accurate prediction of rainfall and of extreme weather events*
- *The problem of seasonal forecasting remains to be solved*
- *However, the prospects for future advances are excellent.*

Nowcasting

For Very-Short Range Prediction — up to 6 hours ahead — direct observational guidance is vital, in addition to computer model guidance. We look at two sources of guidance:

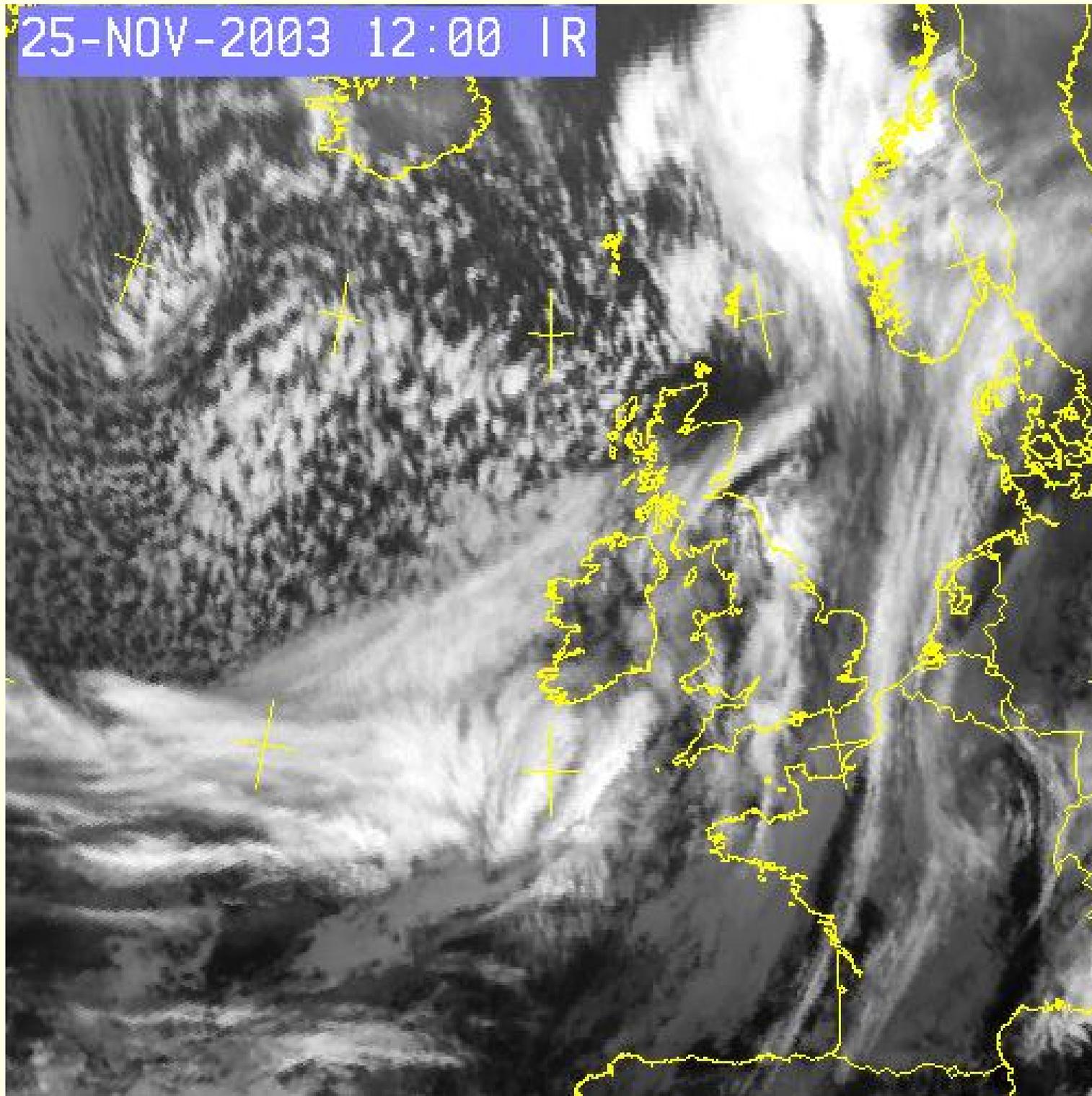
- *Satellite Imagery*

- *Radar Data*

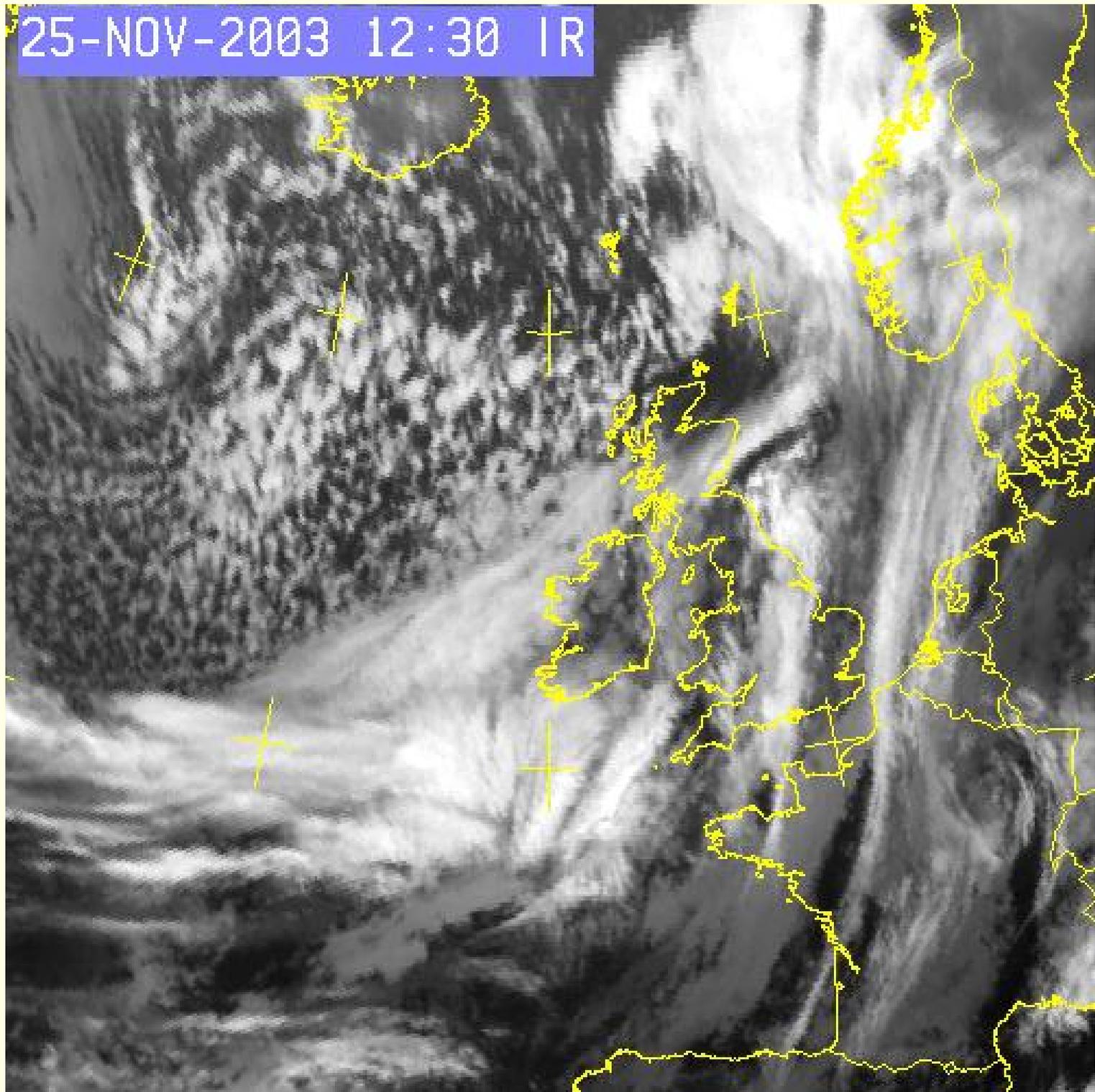
Satellite Imagery

Images from Meteosat, 25 November, 2003, 1200–1800Z

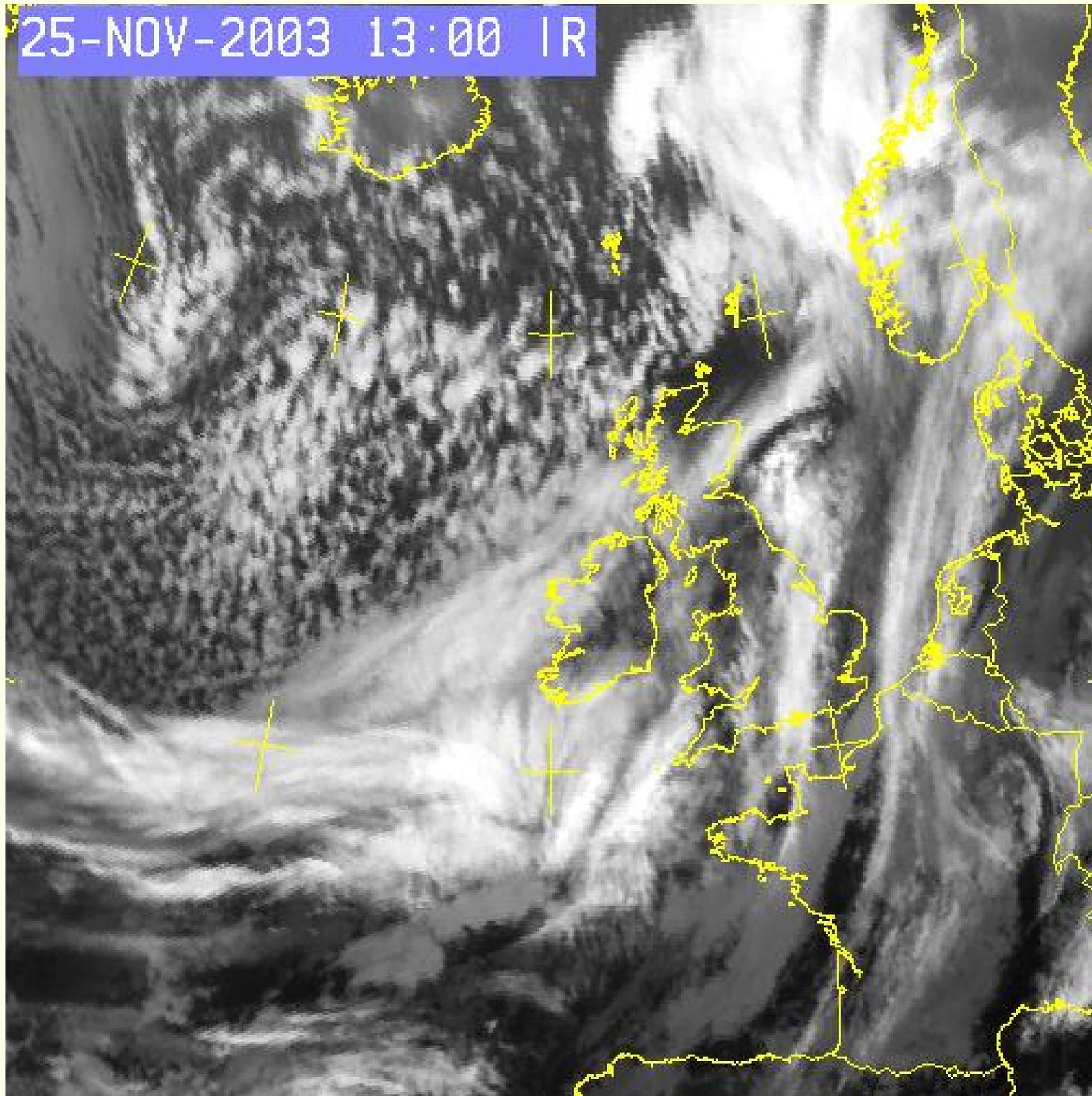
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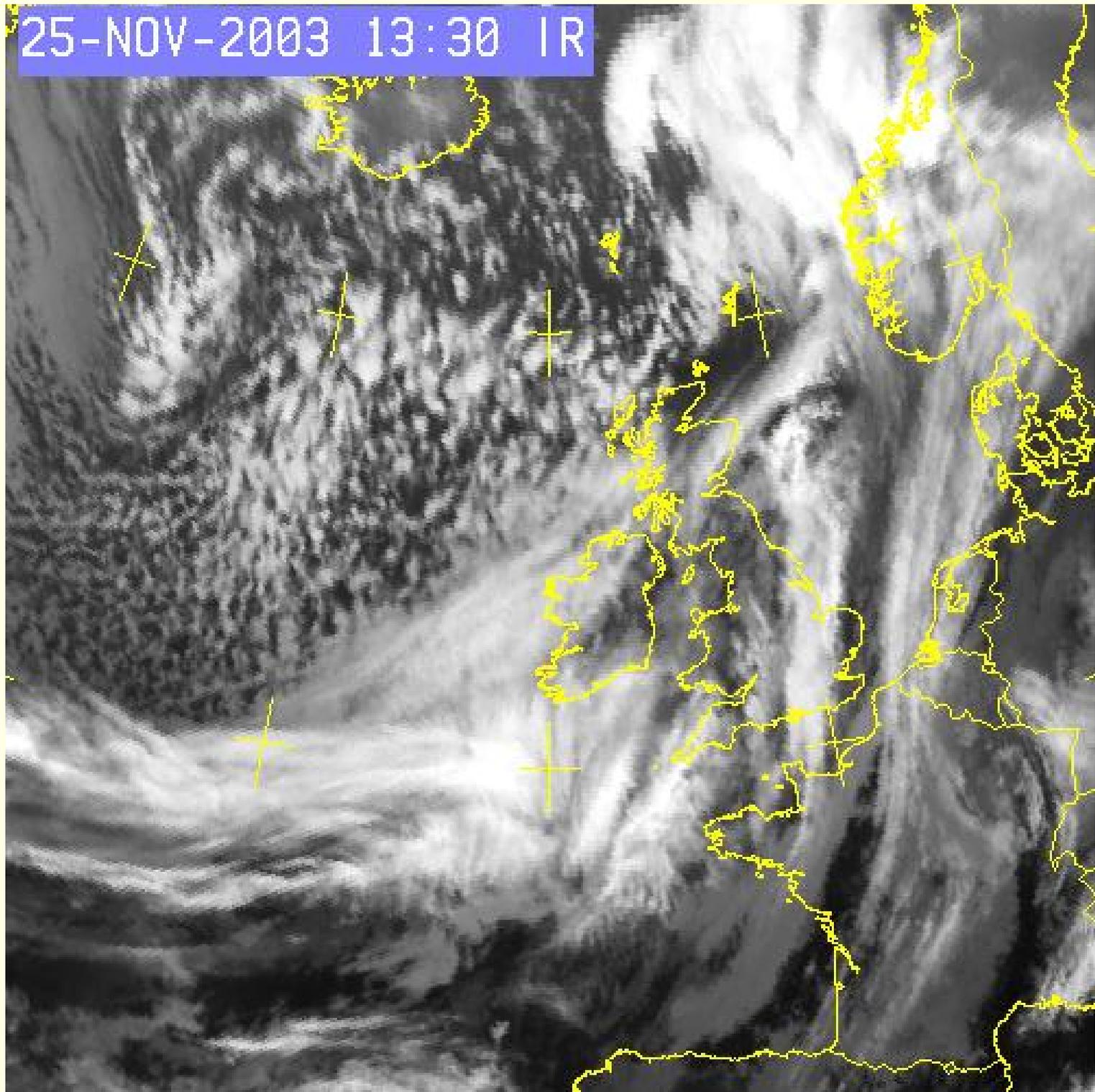
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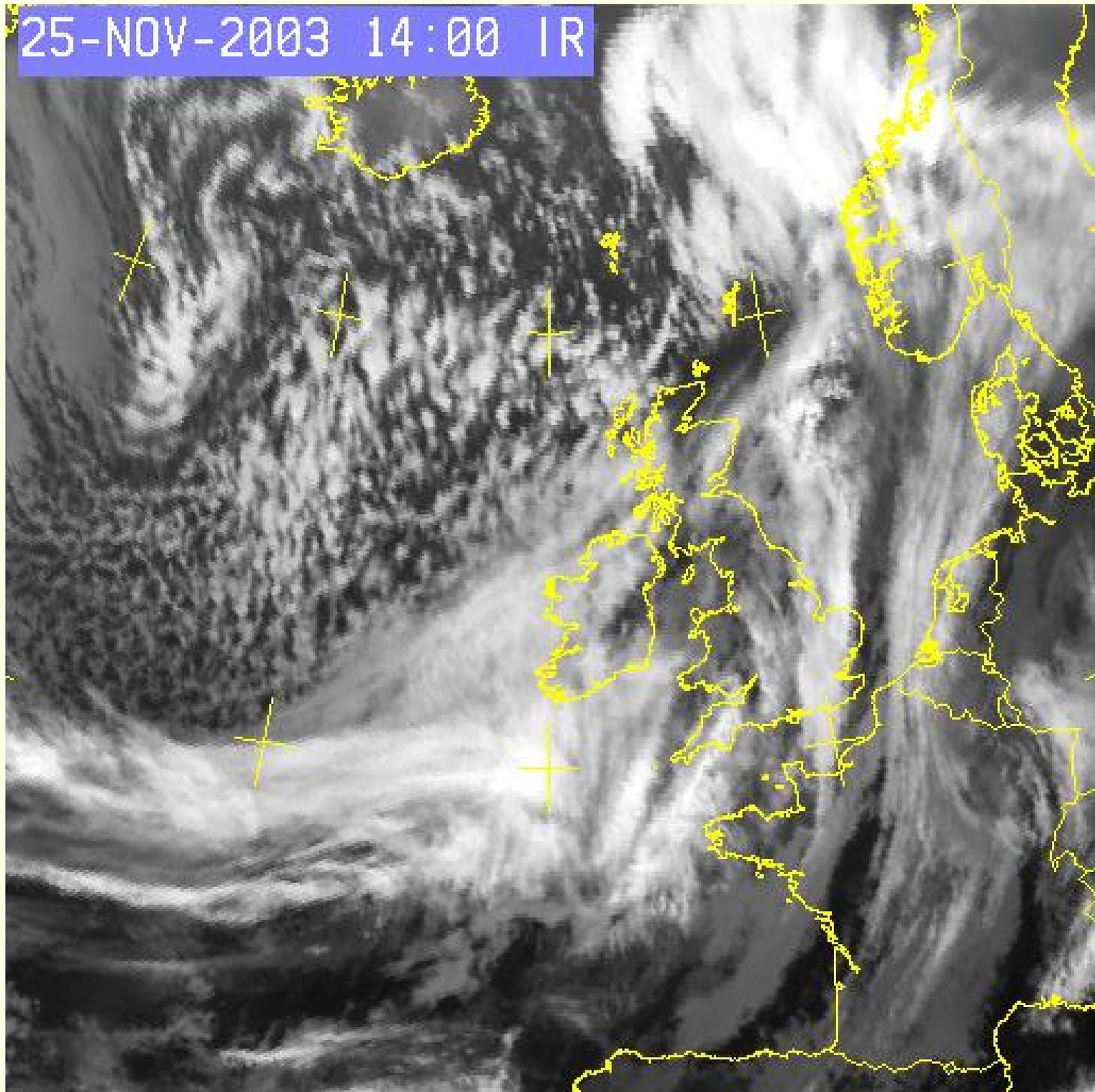
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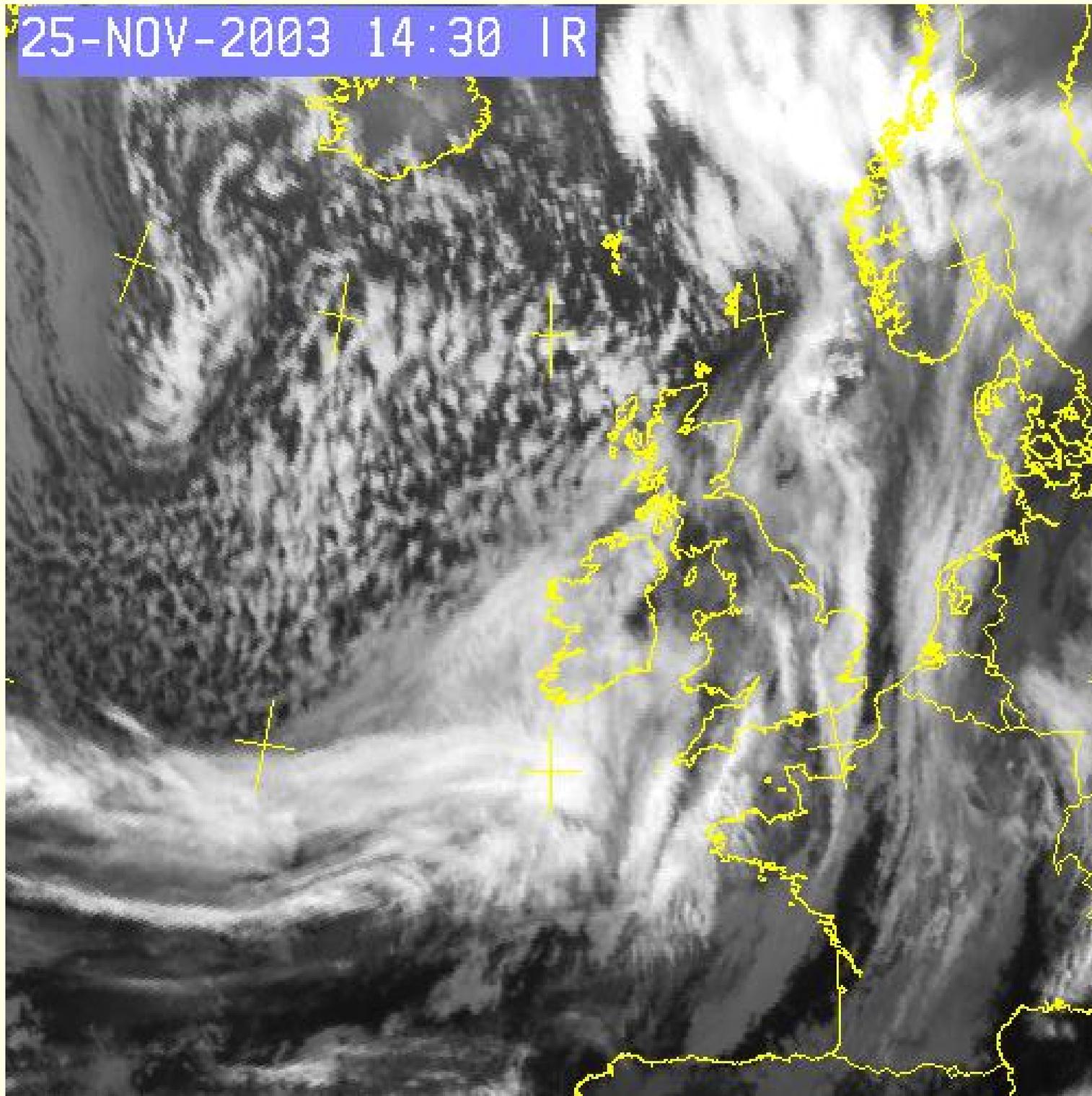
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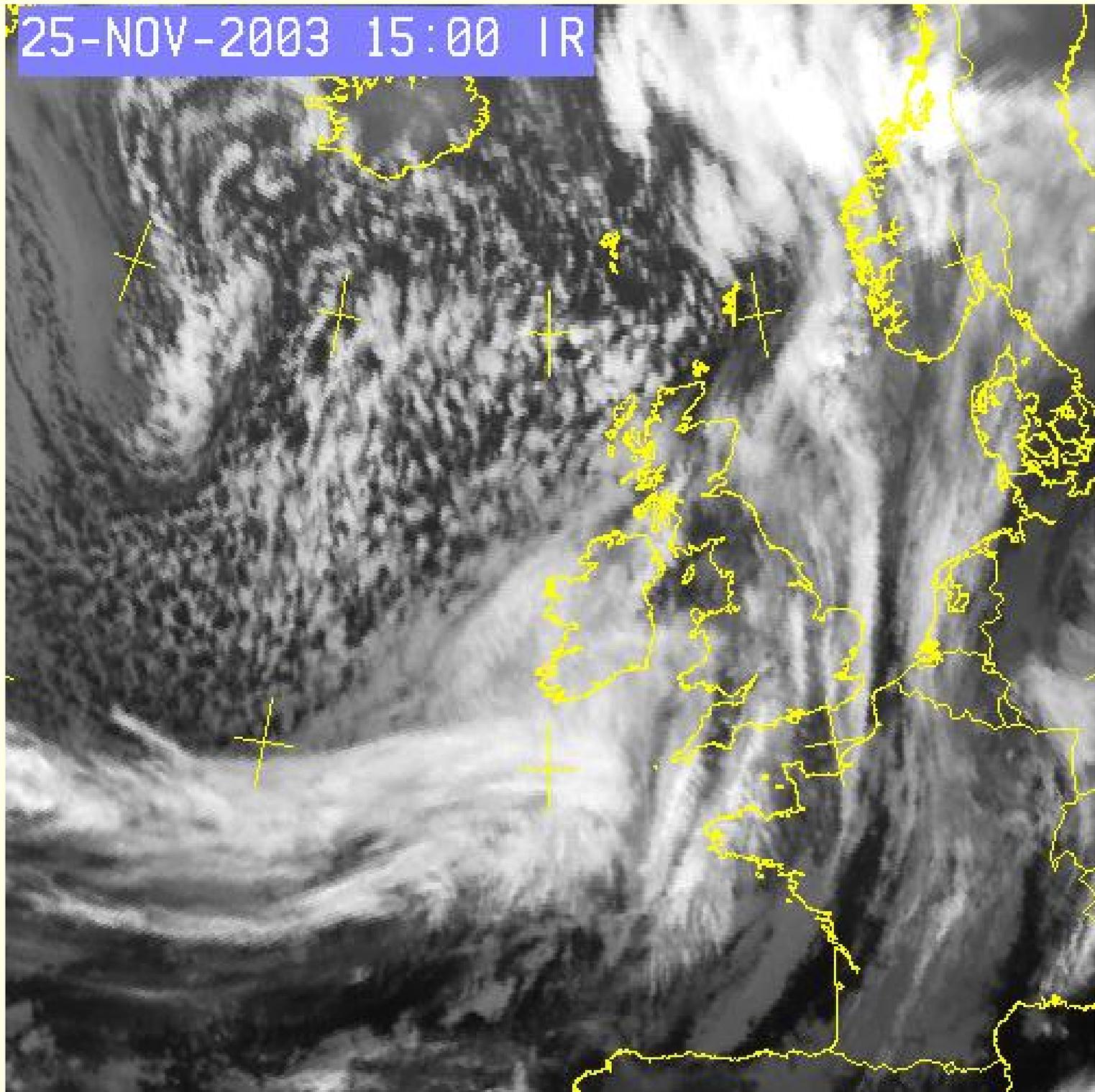
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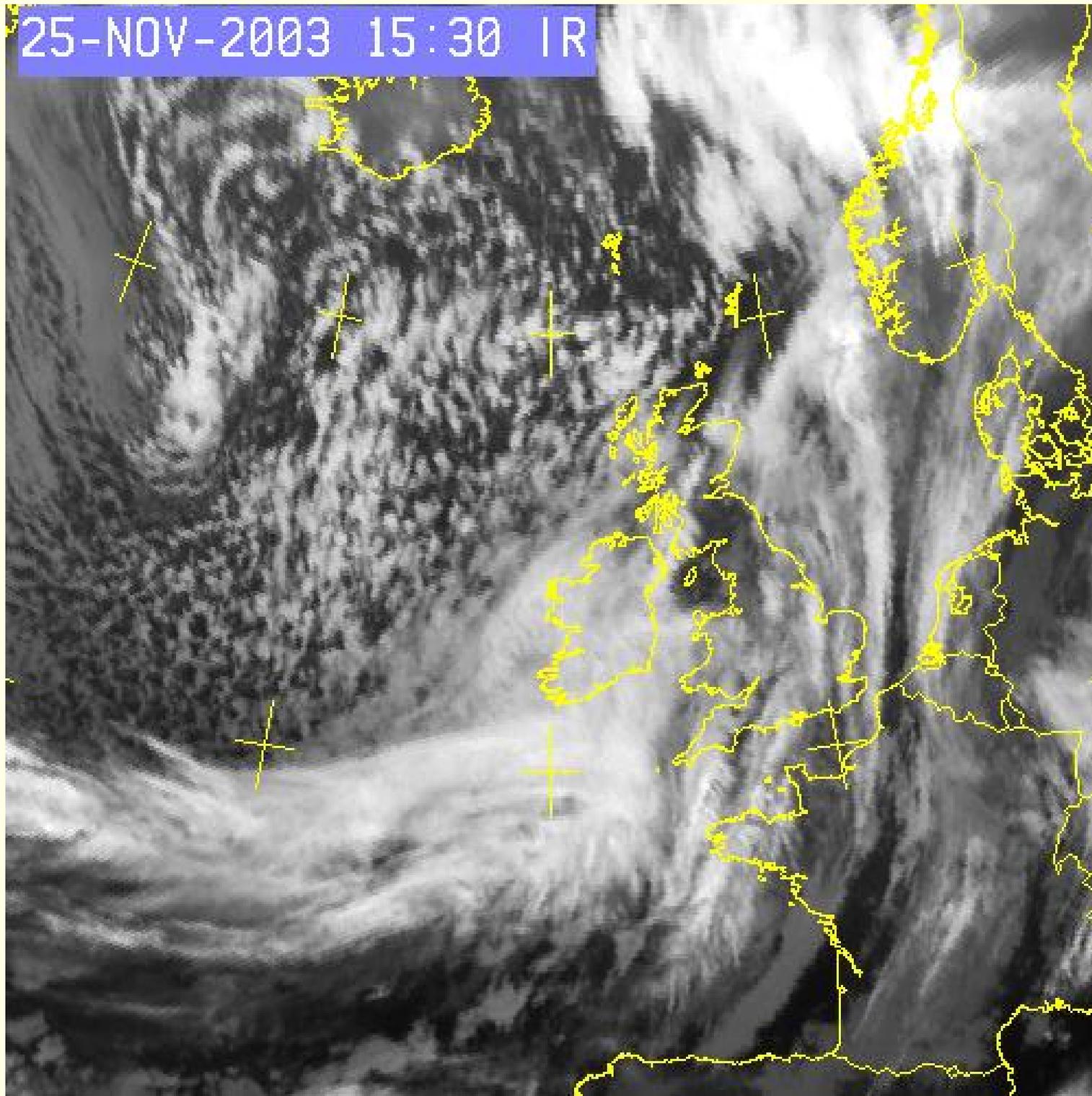
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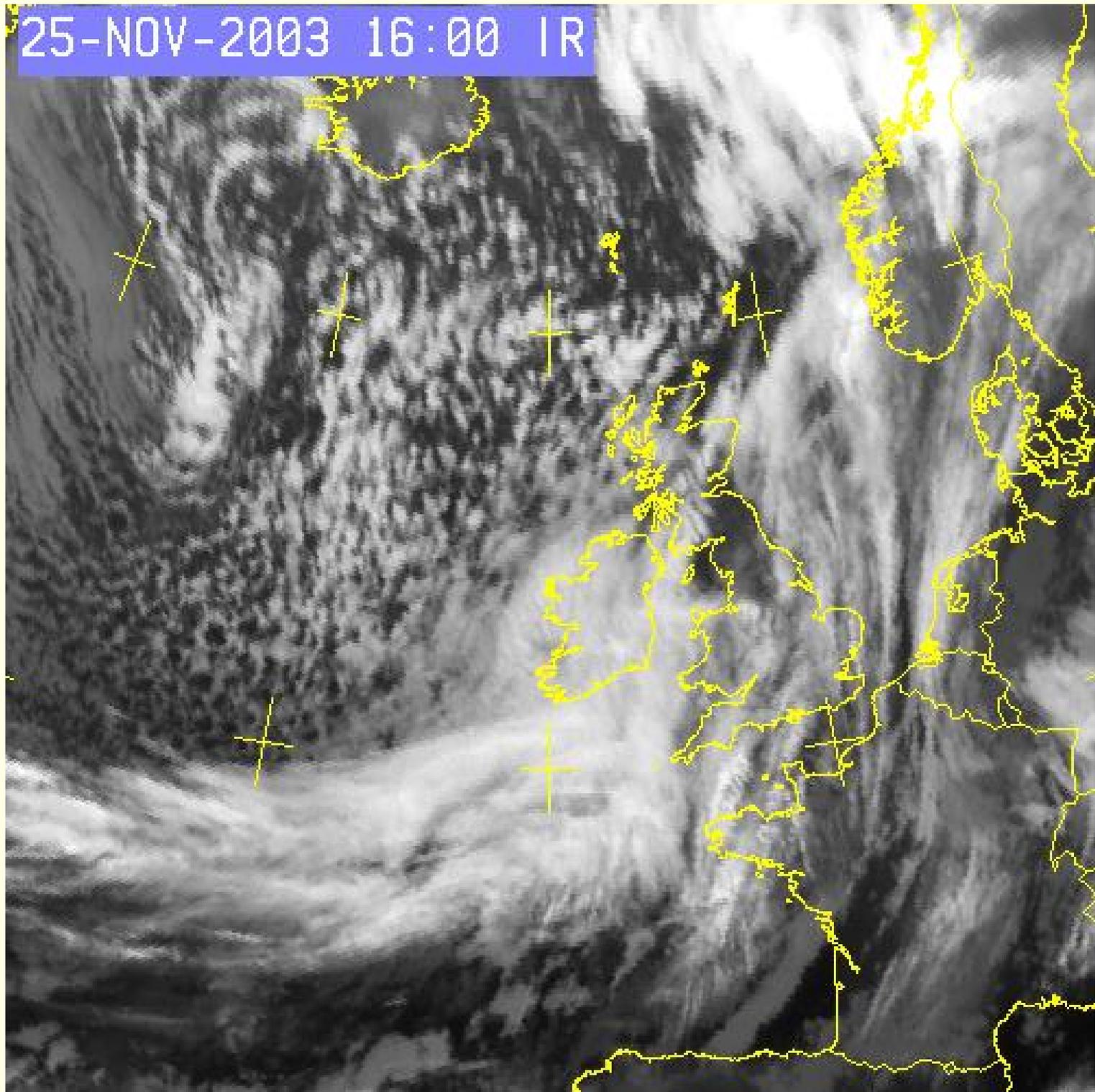
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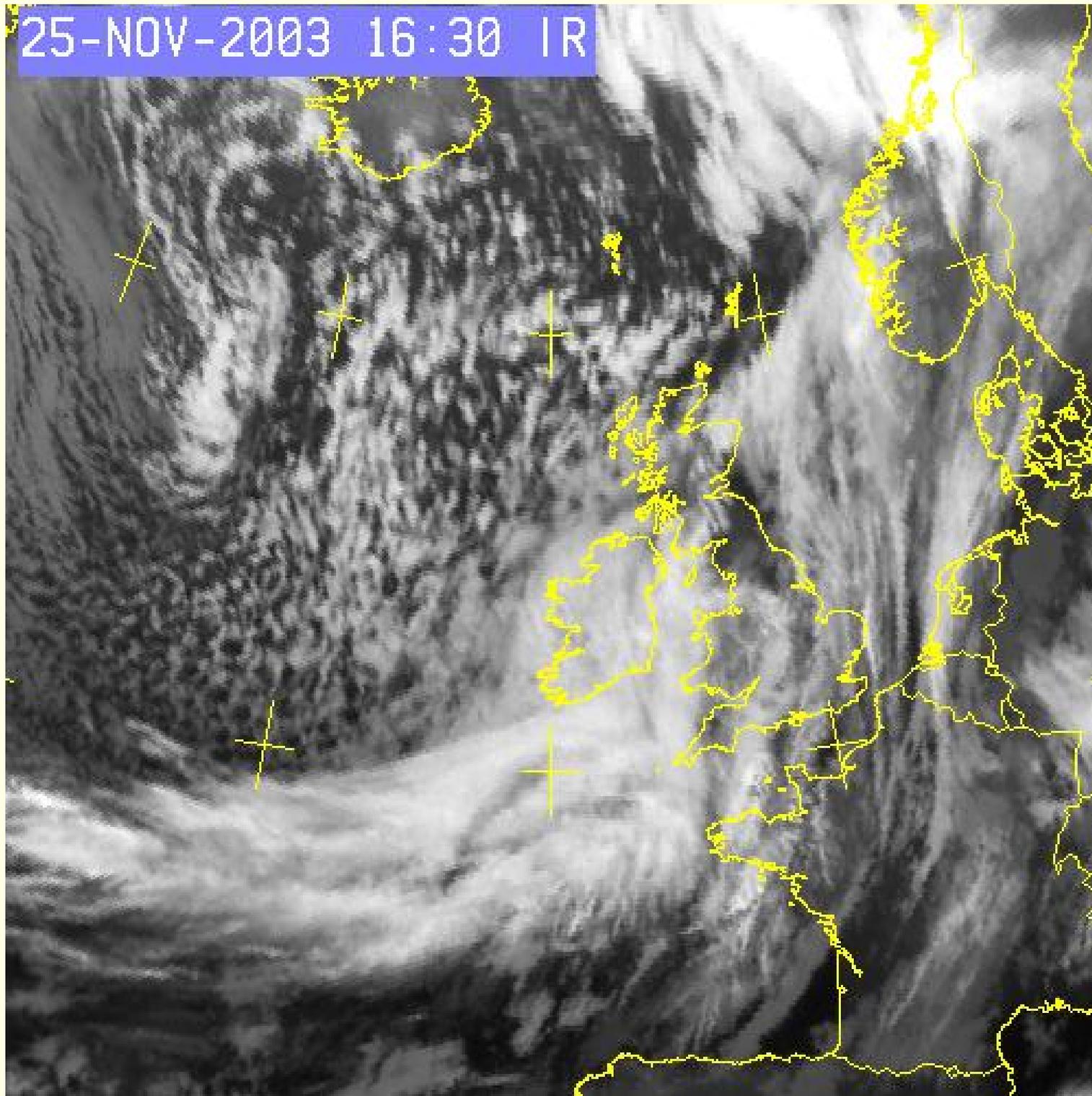
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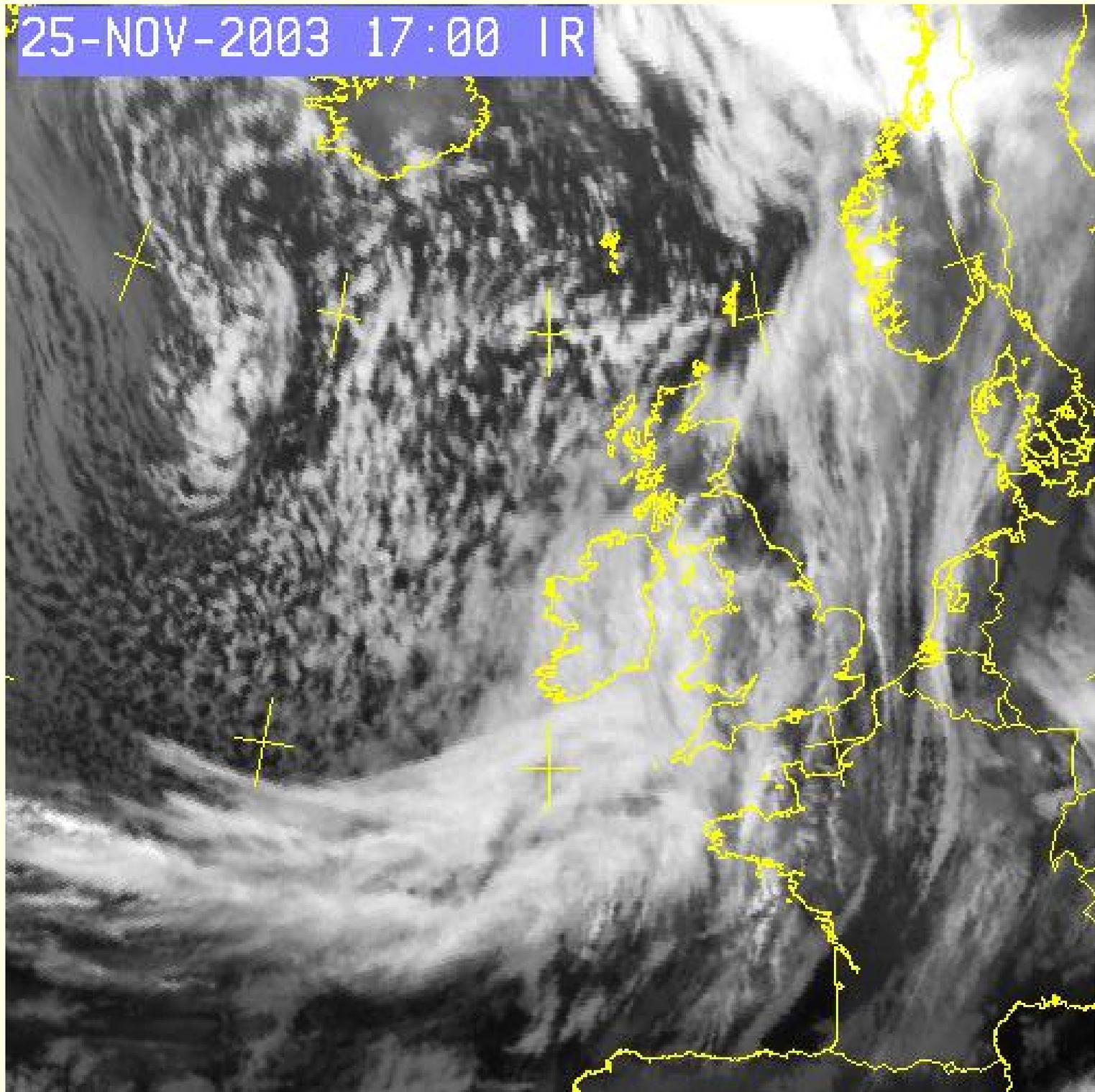
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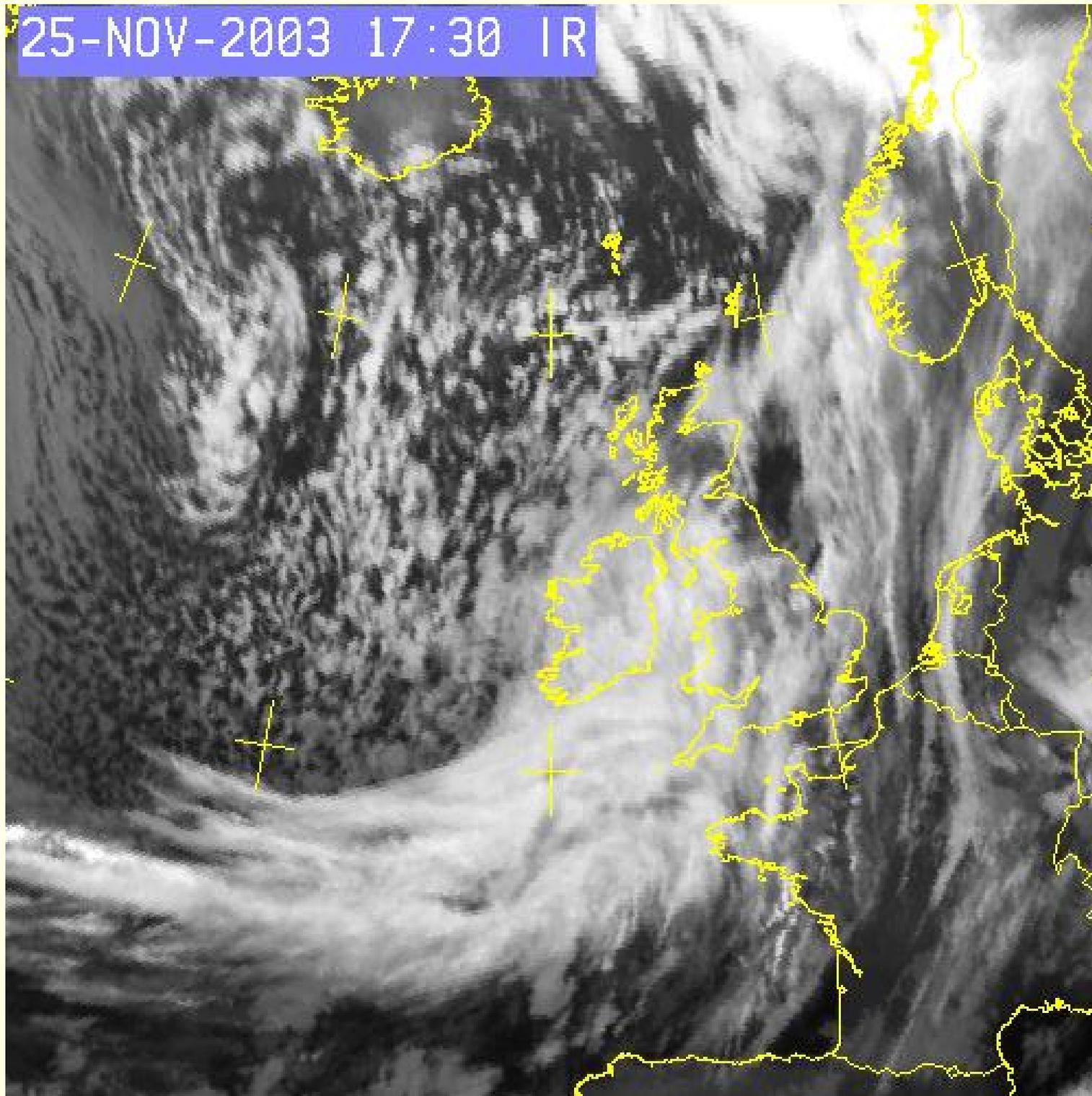
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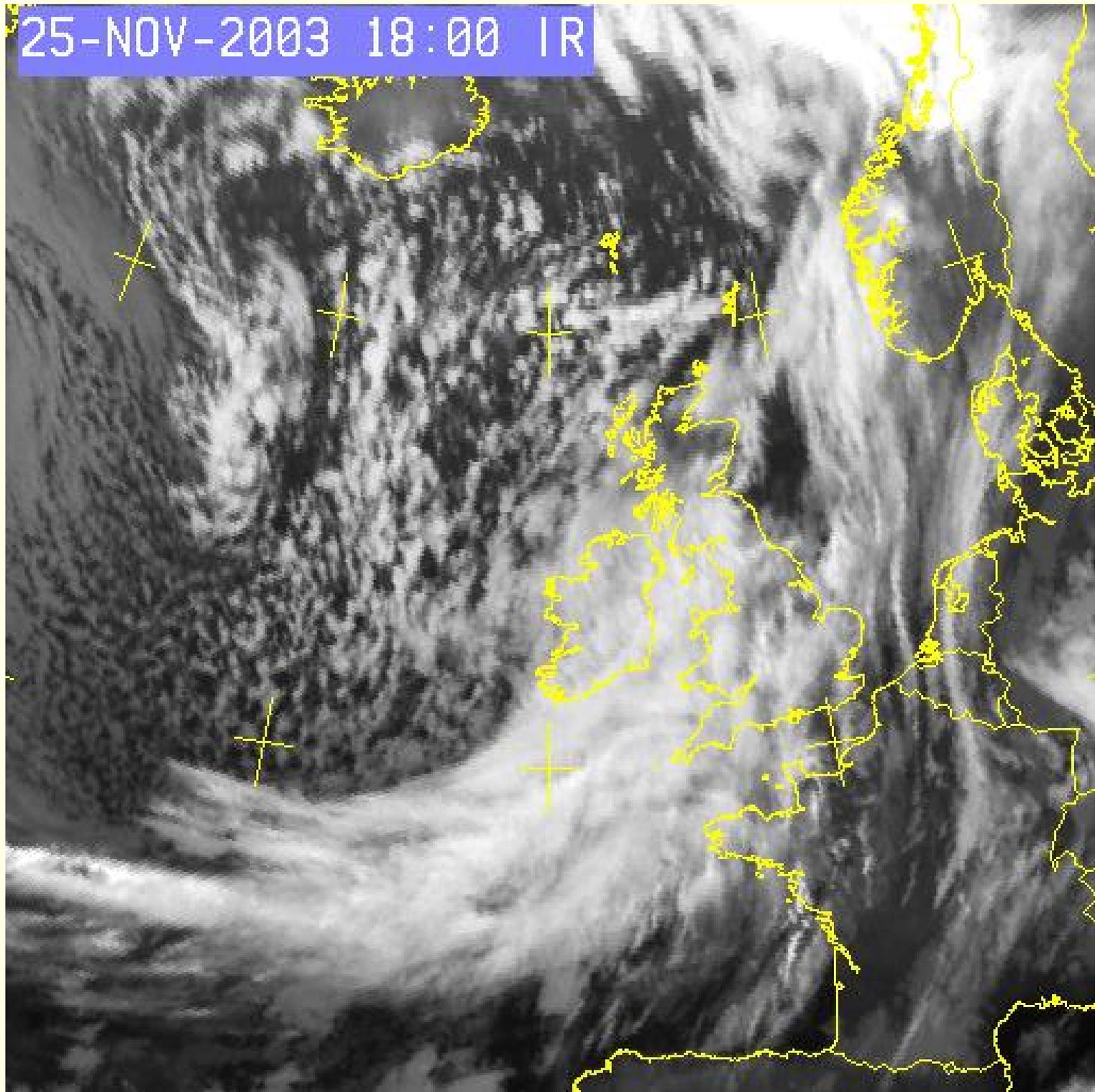
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25-NOV-2003 17:30 IR



25-NOV-2003 18:00 IR

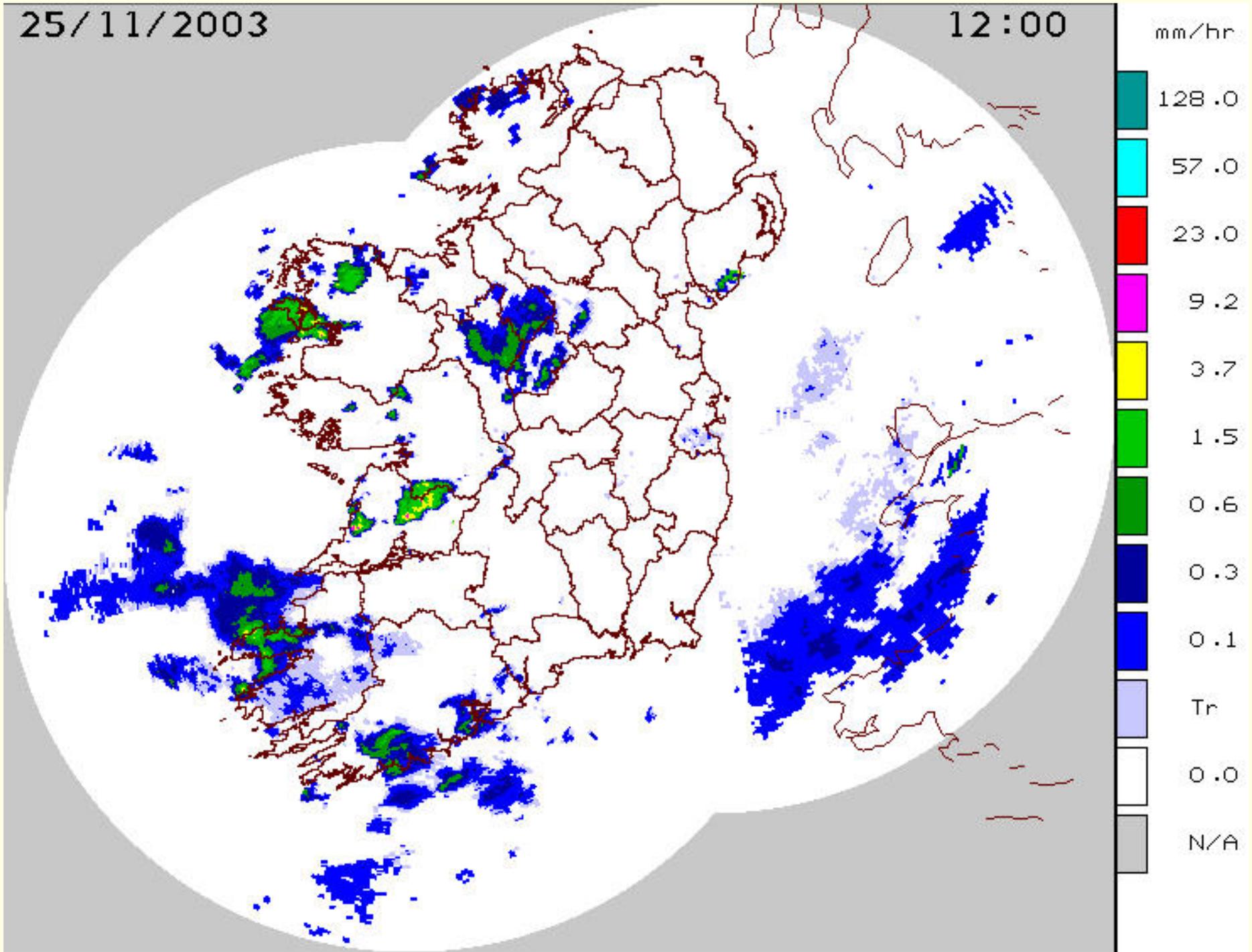


Radar Imagery

25 November, 2003, 12–1800Z

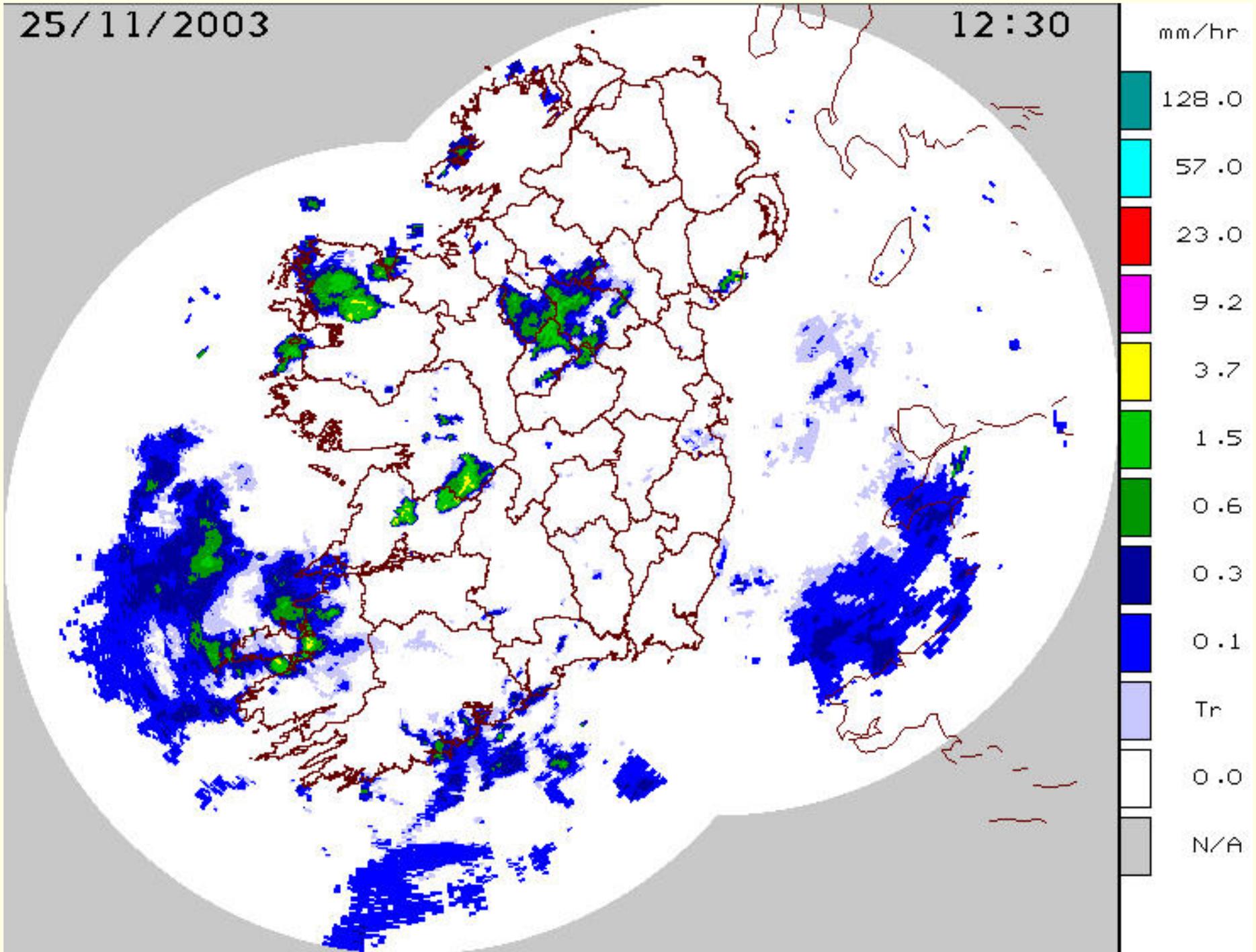
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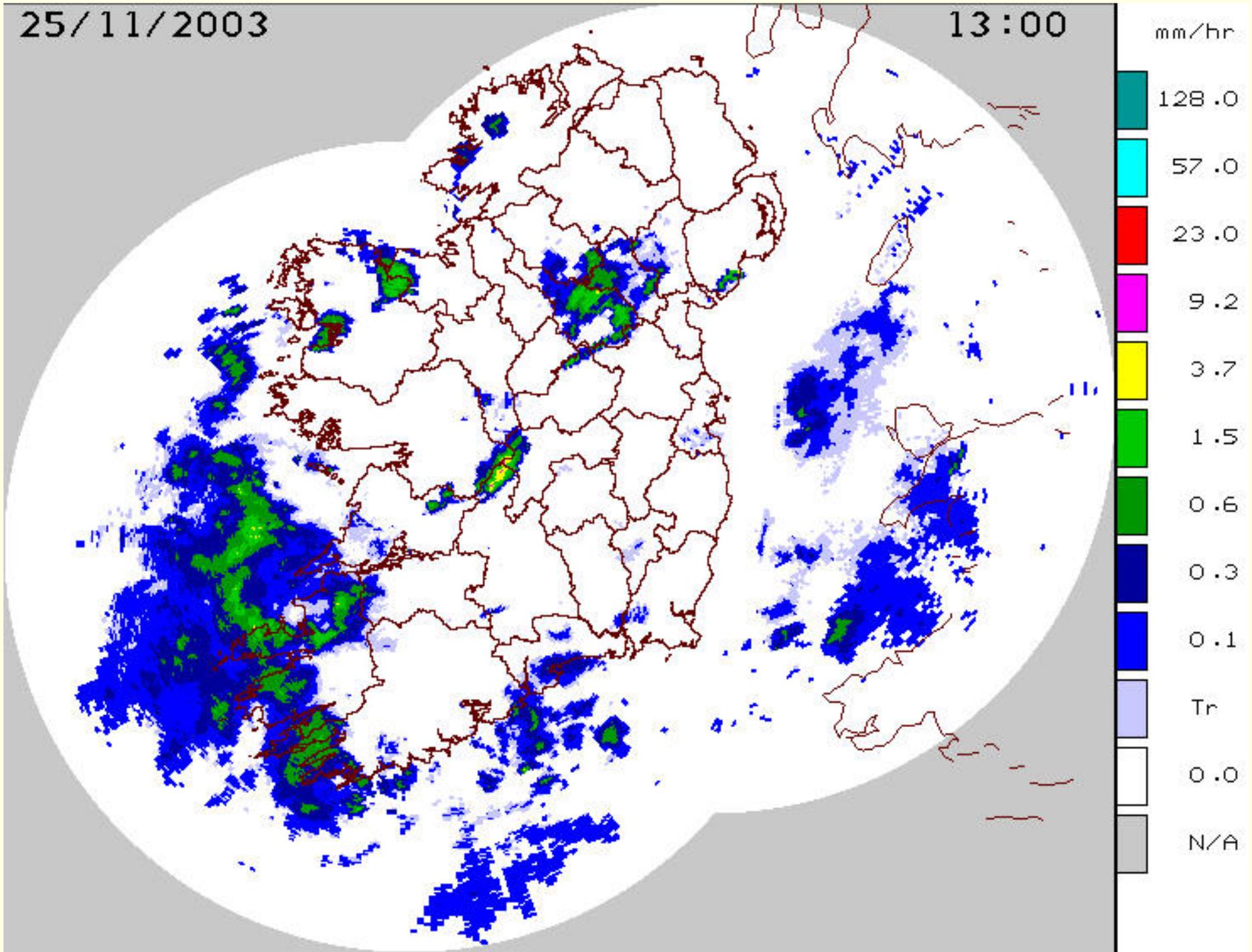
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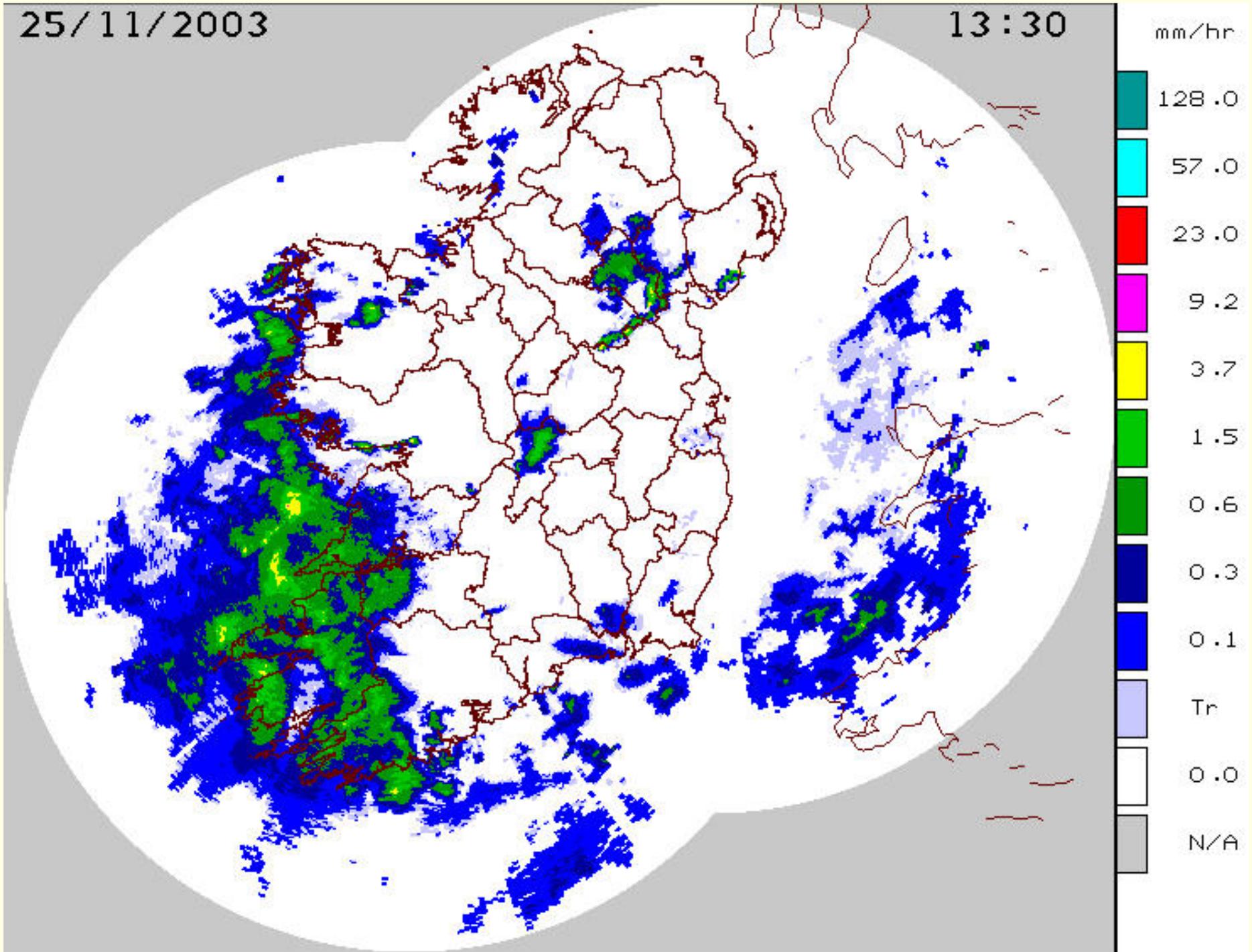
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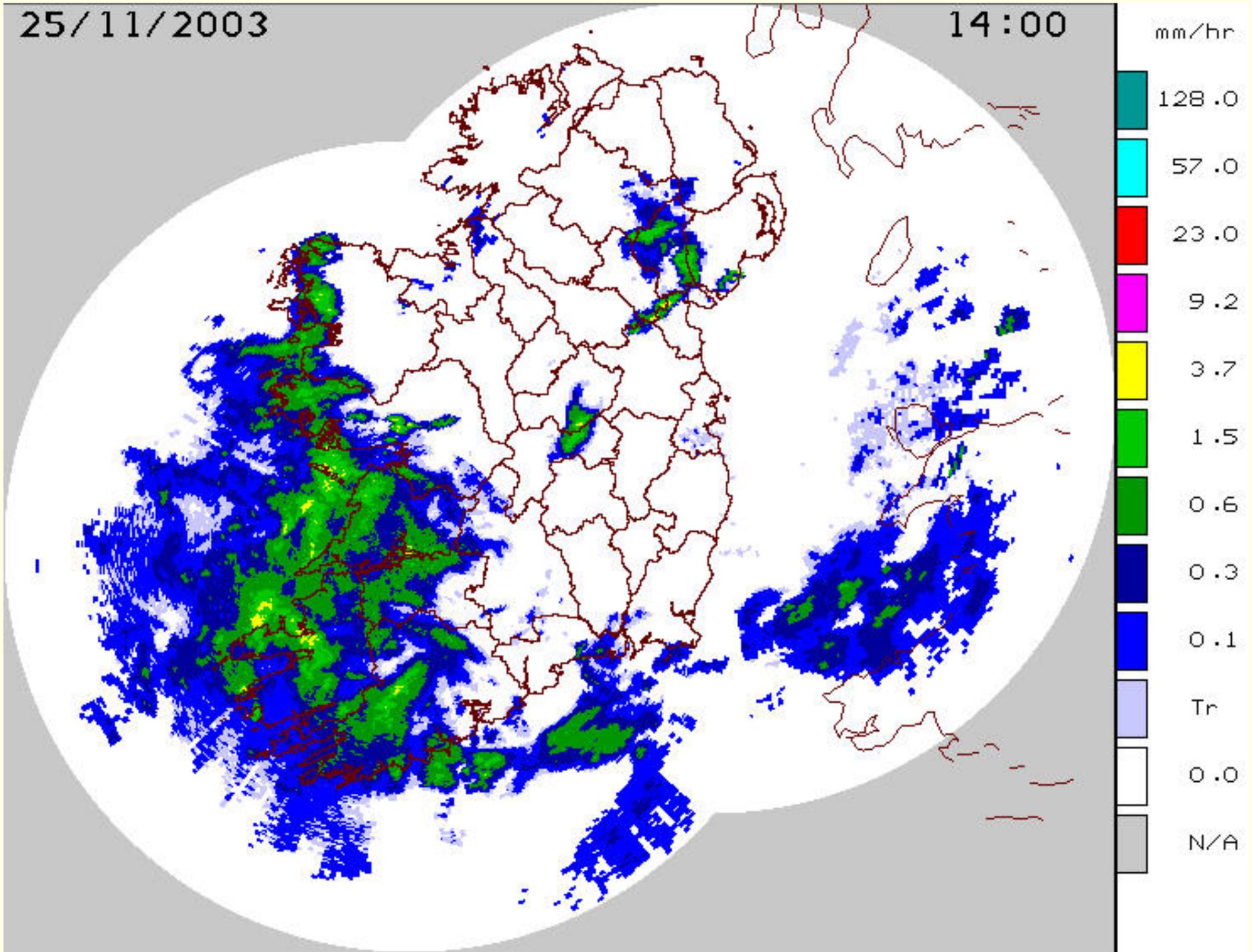
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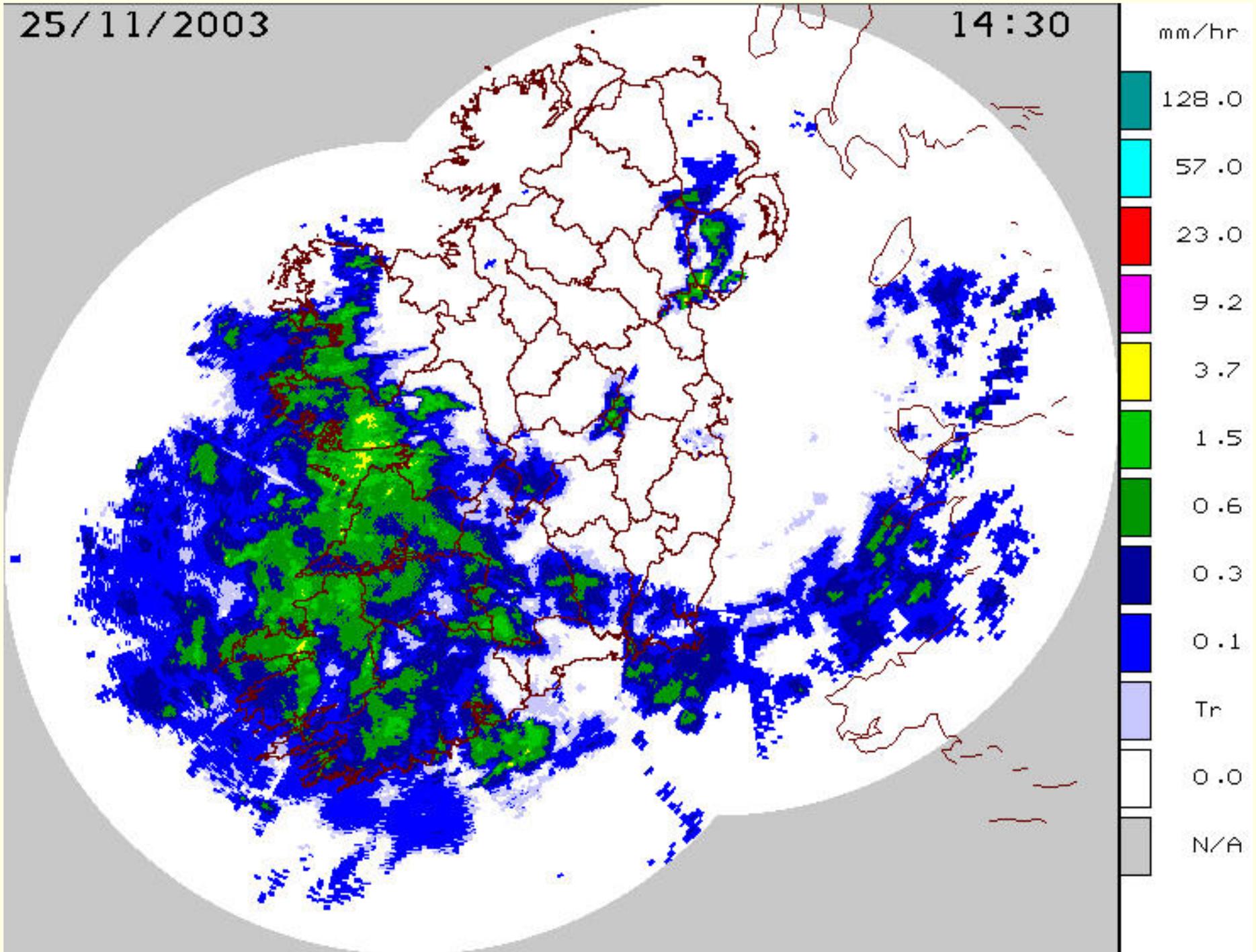
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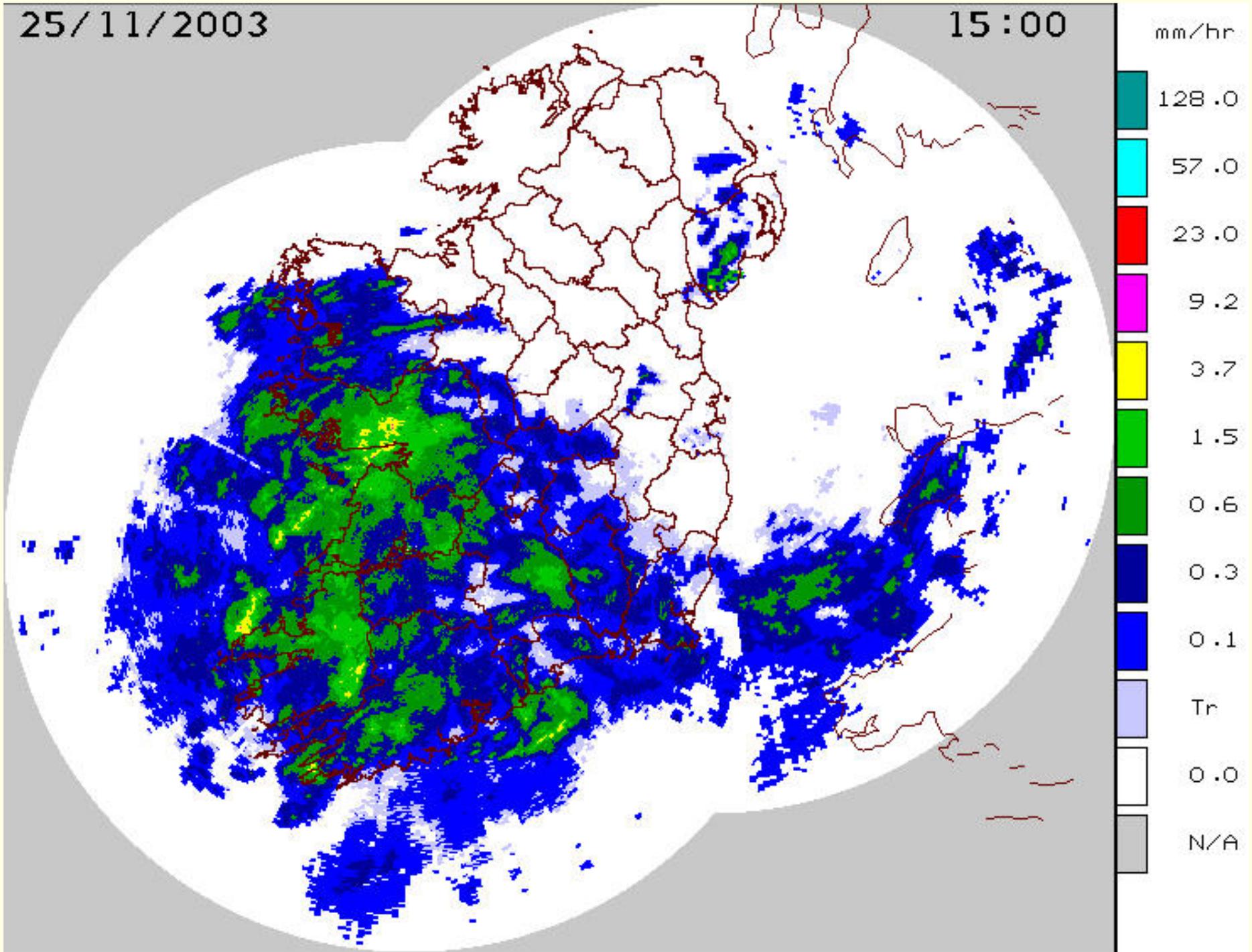
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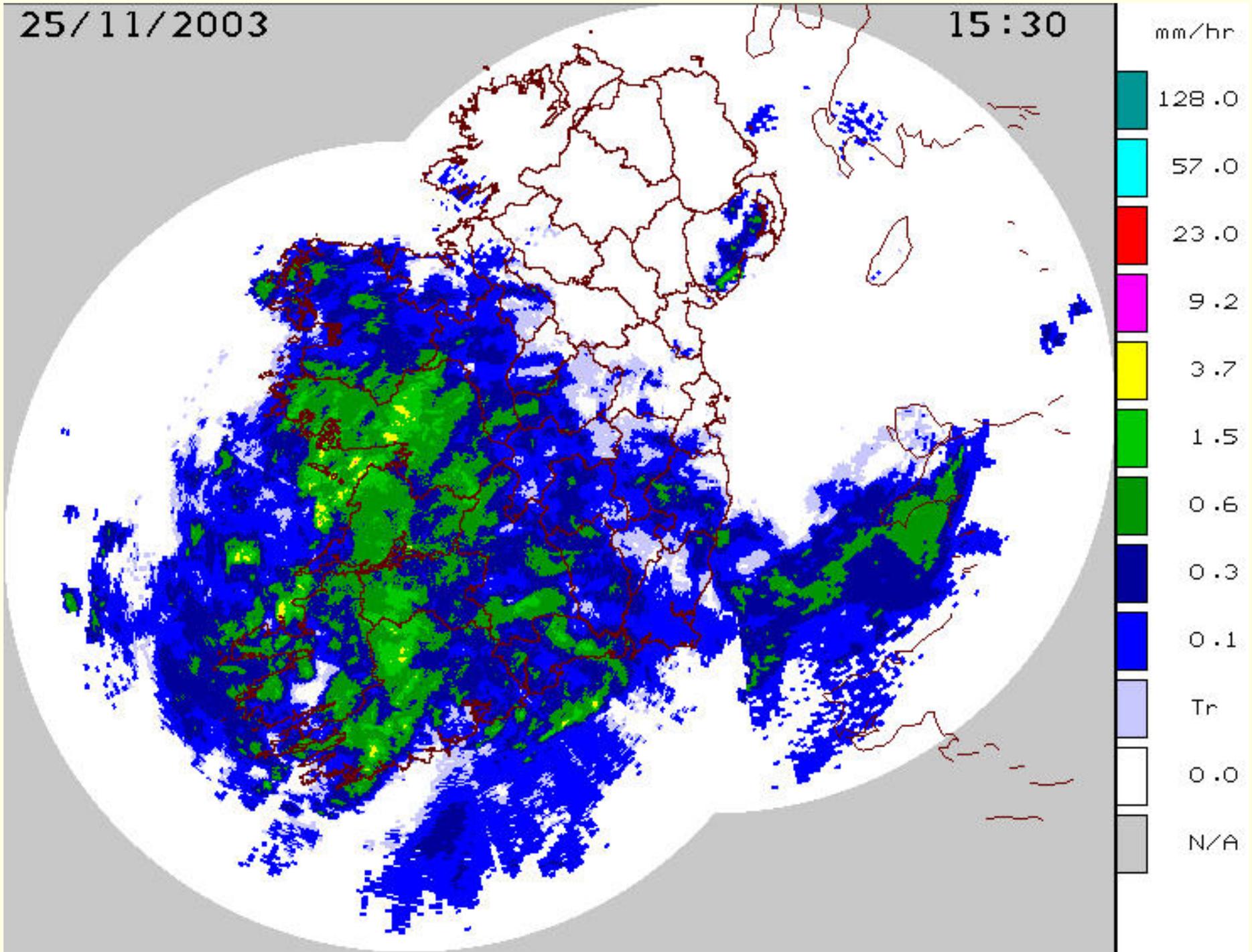
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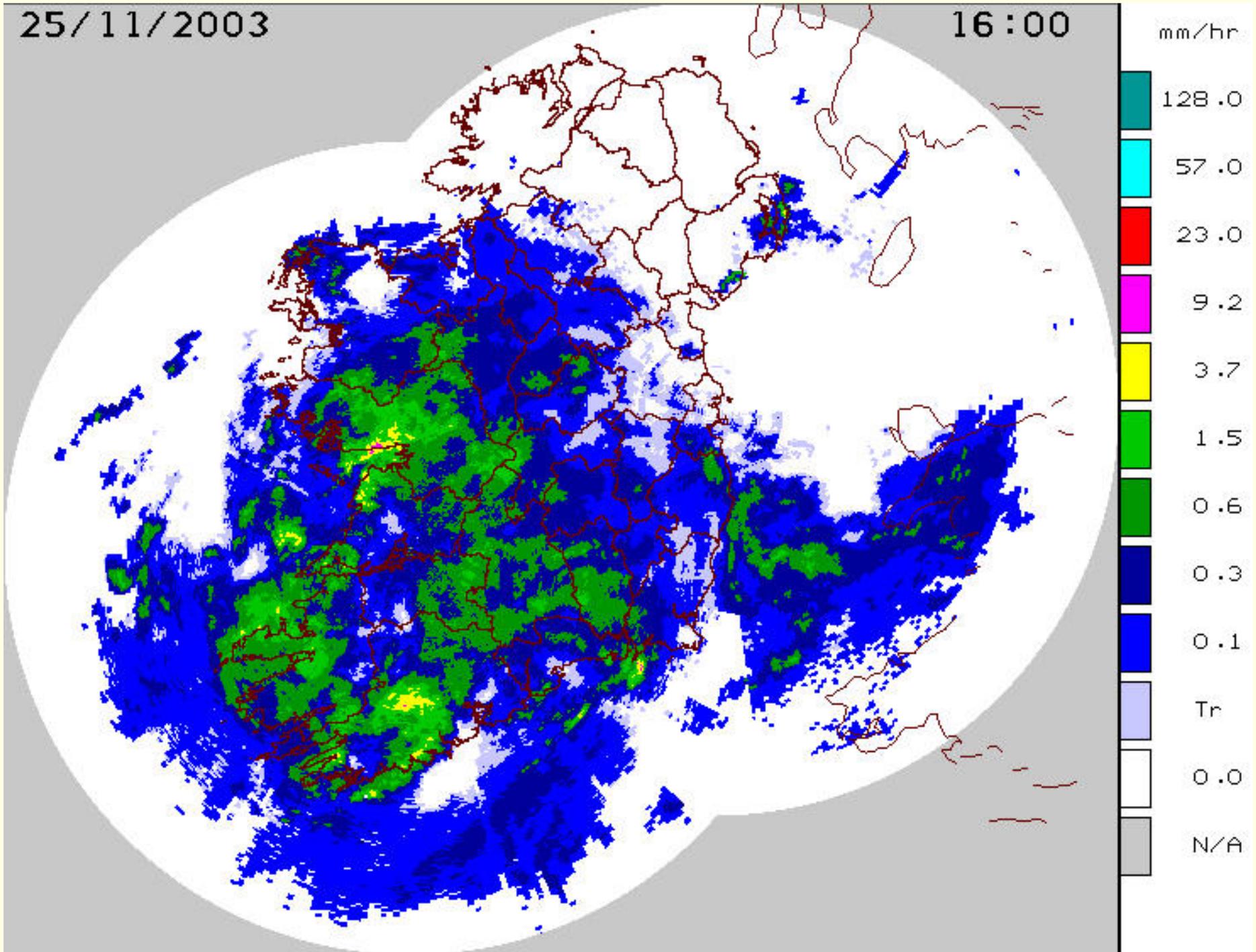
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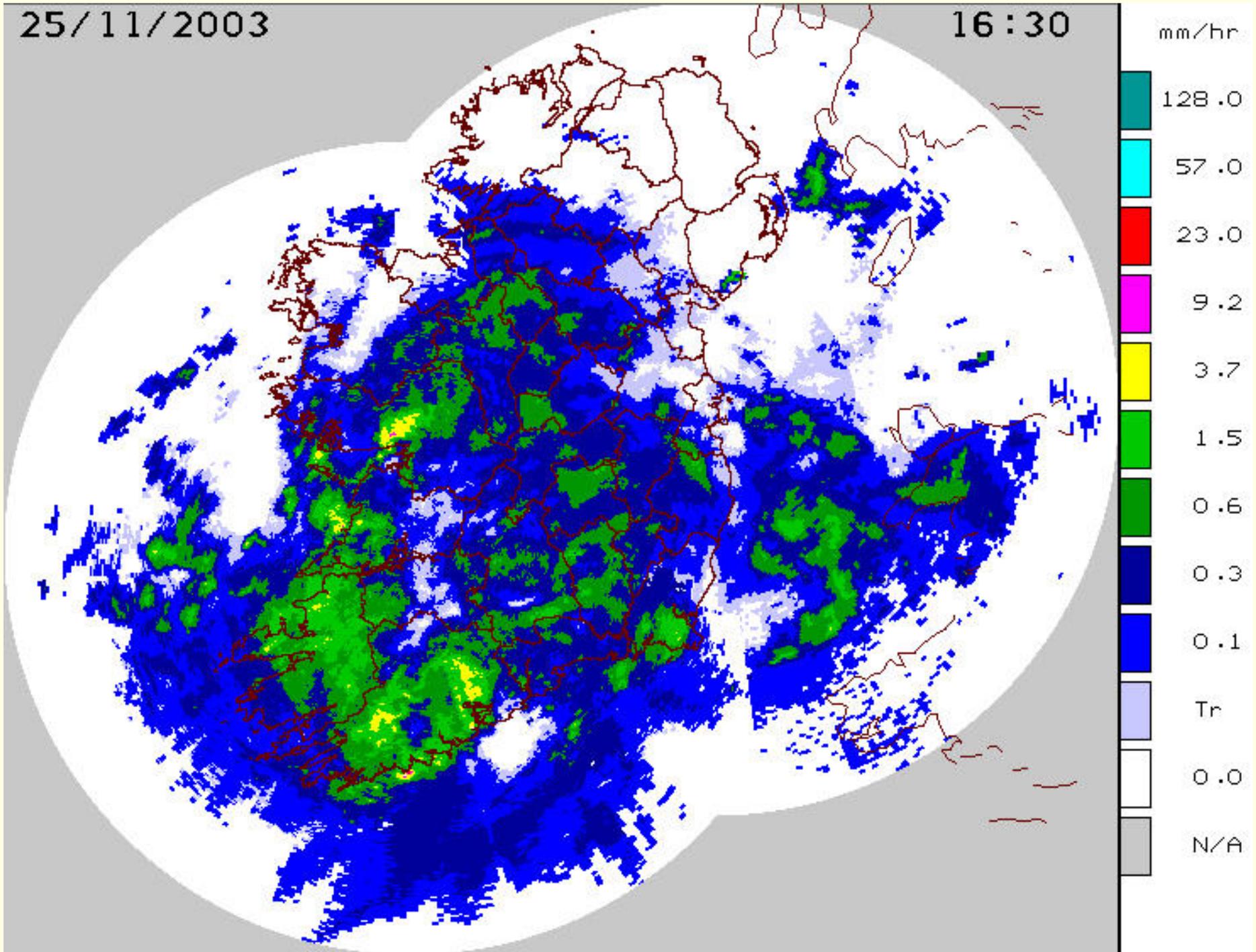
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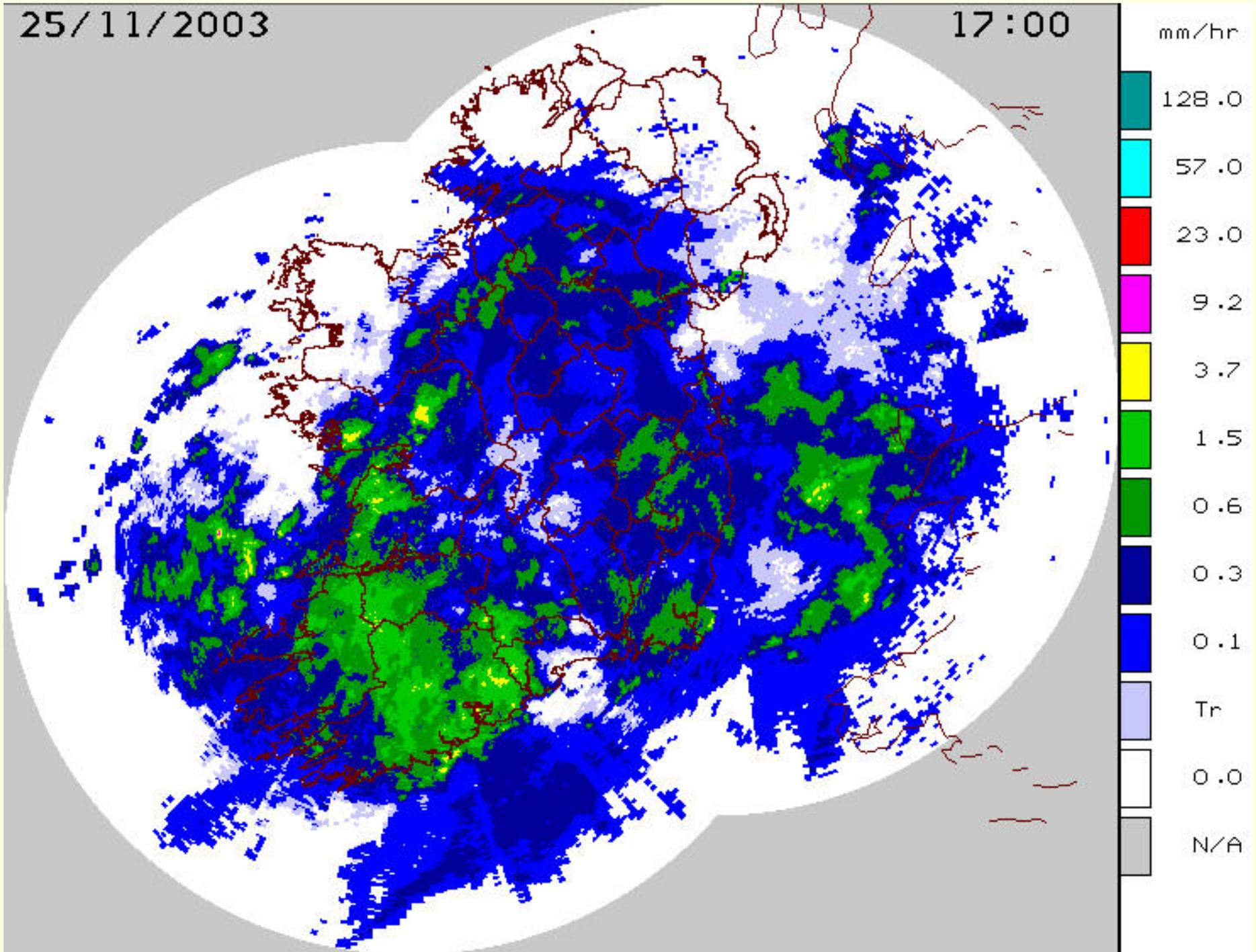
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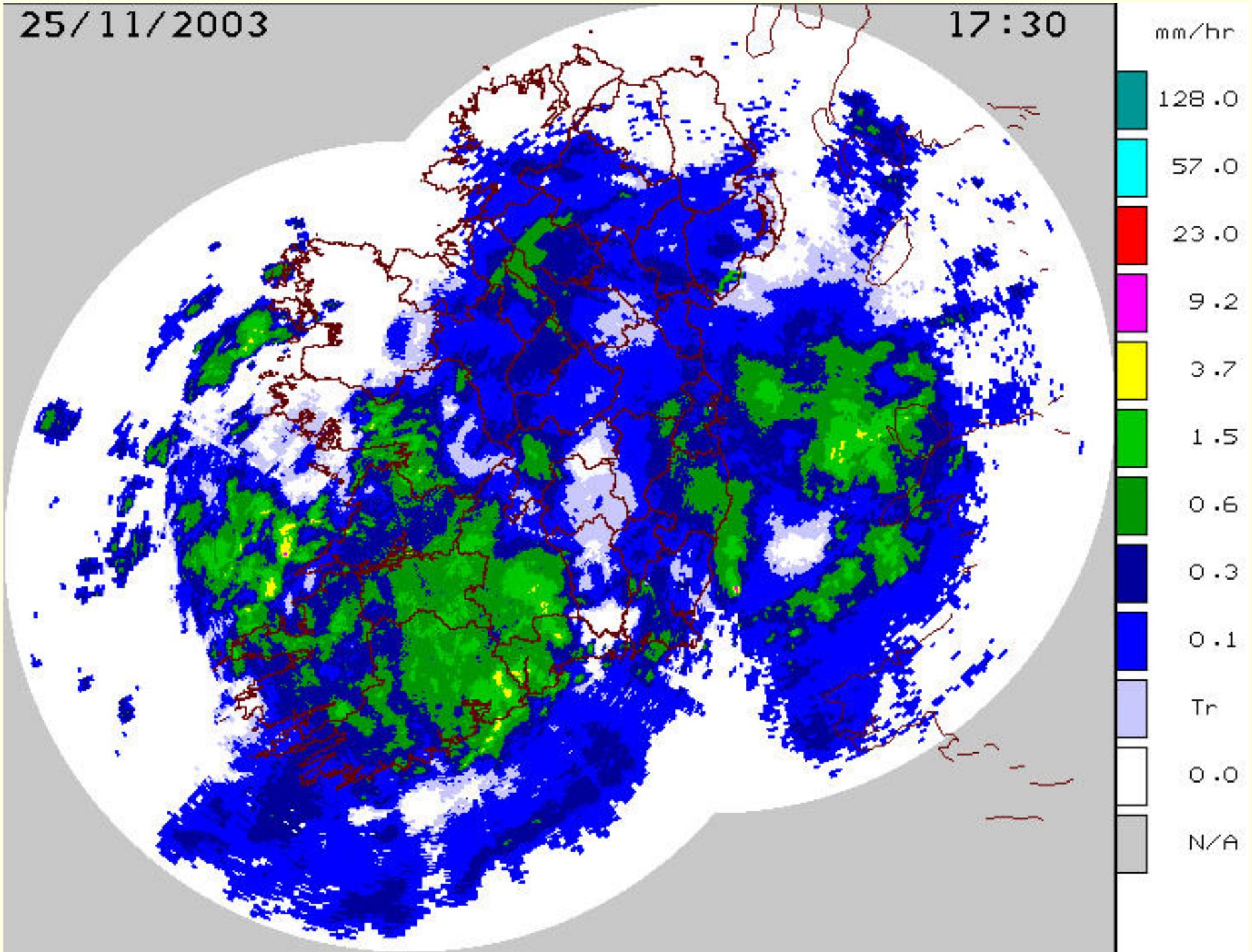
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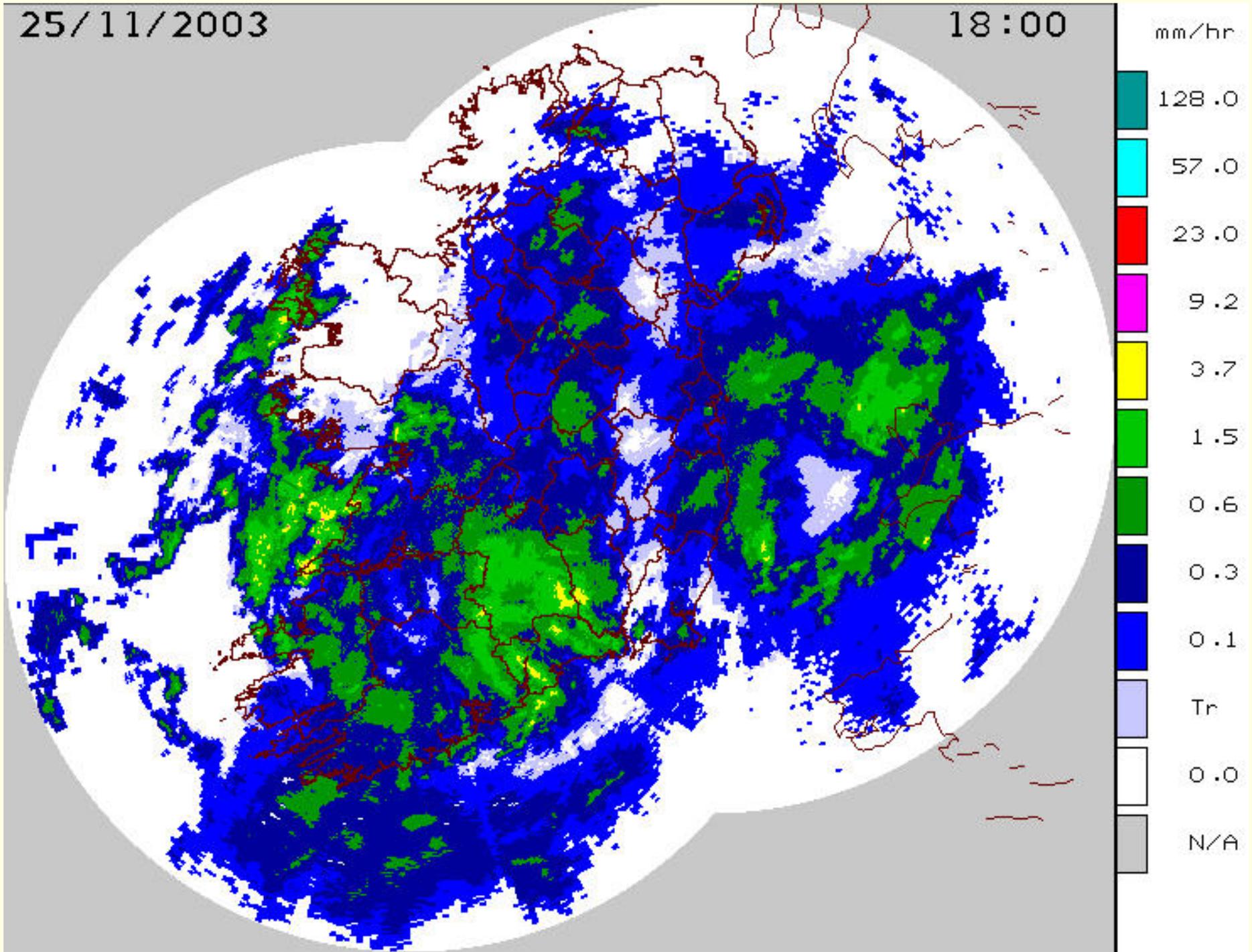
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25/11/2003

18:00



Some Current Developments

■ *Very Short Range Forecasting*

- Quantitative Precipitation Forecasting
- Ensemble Limited Area Modelling

■ *Short to Medium Range Forecasting*

- Better prediction of weather extremes
- Better exploitation of probability forecasts

■ *Long Range Forecasting*

- Extension of Deterministic Range
- Seasonal Forecasting with Coupled Models

Conclusions

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- *Computer forecasts have improved dramatically since the ENIAC integrations.*
- *NWP is an indispensable source of guidance for preparing subjective forecasts.*
- *Beyond the deterministic limit, EPS provides valuable probabilistic forecasts.*
- *Prospects are excellent for further increases in accuracy and scope of NWP.*

**Let us follow the path from information to knowledge!
Let us follow the path from knowledge to wisdom!**



The End

Typesetting Software: \TeX , *Textures*, \LaTeX , hyperref, texpower, Adobe Acrobat 4.05
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