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The Irish Meteorological Service

Weather Forecasting Models in Met Éireann

Eoin Whelan

UCD Seminar

3rd April 2012

Overview

- Background
- HIRLAM Models
- Local Implementation
- Verification
- Development work

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Background

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The Irish Meteorological Service

- Dept of the Environment, Community & Local Government
- *"Monitor, analyse and predict Ireland's weather and climate, and to provide a range of high quality meteorological and related information to our customers"*
- First 'real time' weather observation was transmitted from Valentia Island in Co. Kerry October 8th 1860
- Met Éireann founded in 1936
- HQ in Glasnevin, Dublin

Met Éireann Headquarters

Richardson's Dream

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- British scientist Lewis Fry Richardson's book "*Weather Prediction by Numerical Process*"
- No computers, so …
- Work force of 64,000 people with mechanical calculators
- Leader in centre with coloured light to coordinate the forecast

Some computer history

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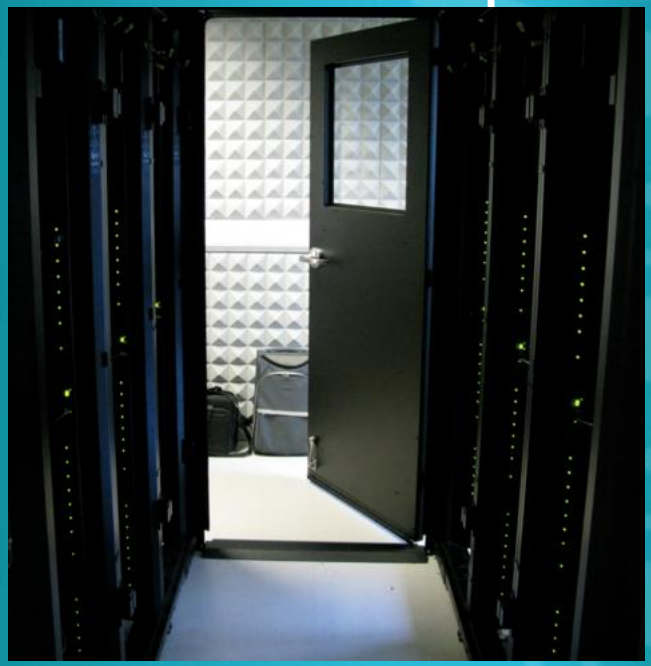
- 1951: ENIAC forecasts, first successful numerical simulation
- 1954: SMHI first to have operational forecast model

- 1978: TCD/Met Éireann – DEC 20/40
  - SMHI quasi-geostrophic model
- 1979: Met Éireann – DEC 20/50 – fastest computer in Ireland
  - Yugoslavian primitive equation model on 5 levels + SMHI OI Analysis
- 1986: Met Éireann joins HIRLAM consortium
- 1994: Met Éireann – SGI R10000 – first multi core computer
- 2001: Met Éireann – 18 core IBM cluster
- 2007: ICHEC

ICHEC

- Irish Centre for High End Computing
- Used operationally since June 2007
- Guaranteed use of 16 nodes
- Collaboration with research & development

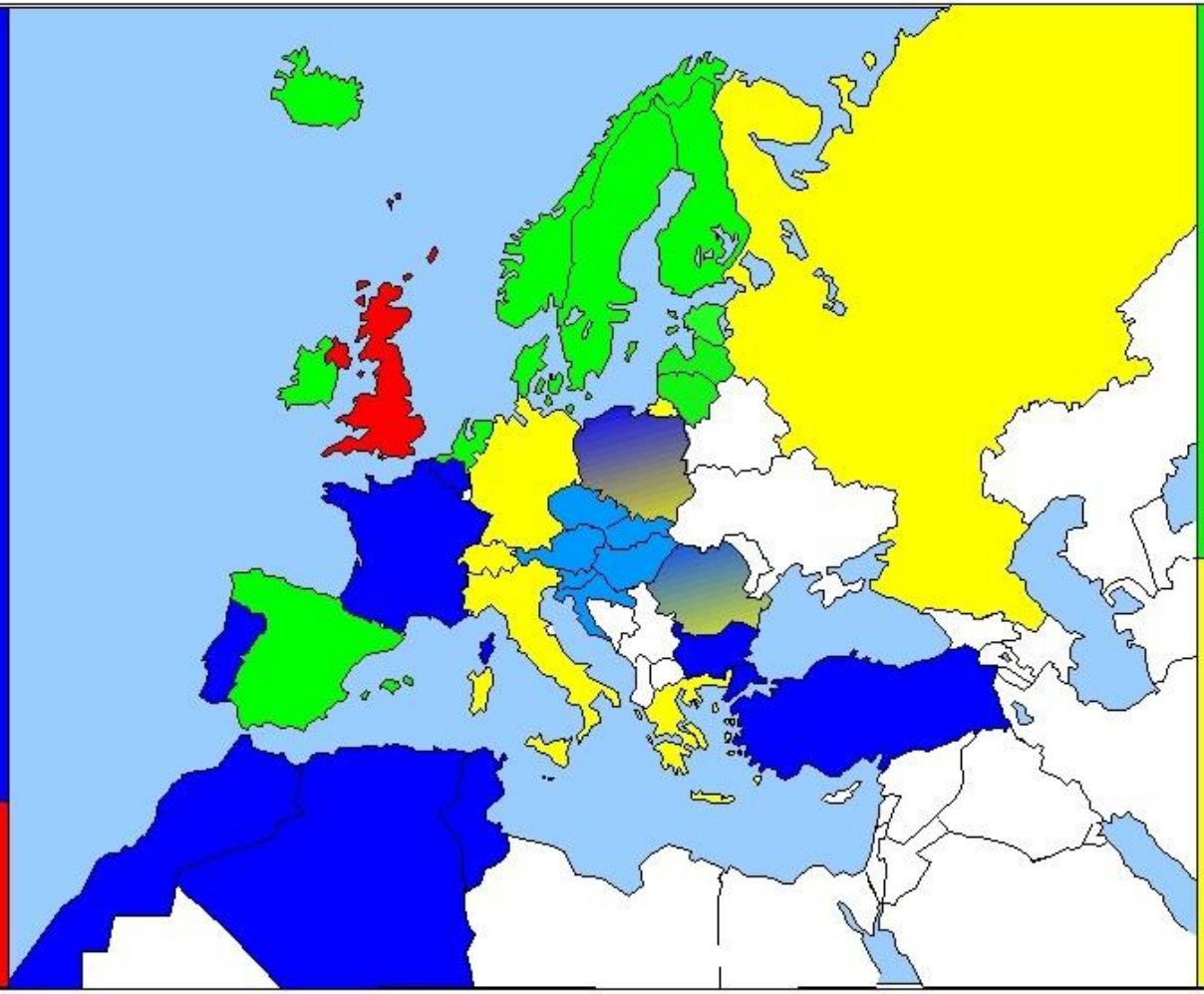


SRNWP Consortia in Europe

ALADIN
Algeria
Belgium
Bulgaria
France
Morocco
Poland
Portugal
Tunisia
Turkey

Austria
Croatia
Czech Rep.
Hungary
Romania
Slovakia
Slovenia
LACE

UKMO
United Kingdom



HIRLAM
Denmark
Estonia
Finland
Iceland
Ireland
Netherlands
Norway
Spain
Sweden
(Latvia)
(Lithuania)

COSMO
Germany
Greece
Italy
Poland
Romania
Russia
Switzerland

Met Office

COSMO

HIRLAM Consortium

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- HIRLAM: High Resolution Limited Area Model
- Co-operation of 10 NMSs initiated in 1985
- Met Éireann joined in 1986
- Météo France & ALADIN cooperate with research
- NMSs commit at least 2 staff each year
- Other contributors involved as well

HIRLAM Consortium

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- Multiple phases since 1985
- HIRLAM-B since 1st January 2011
- Cooperation with MF & ALADIN consortium
- Main goals:
  - Development of Harmonie
  - Development of GLAMEPS
  - Develop cost-effective operational cooperation

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HIRLAM Models

HIRLAM Models

- HIRLAM: High Resolution Limited Area Model (HIRLAM-A)
- Weather model on 5-20km grid

- Harmonie: HIRLAM-Aladin Research in Mesoscale Operational NWP In Eurometet (HIRLAM-B)
- Weather model on kilometre scale grid
- Met Éireann was the 1st HIRLAM NMS to make Harmonie operational

Harmonie development

- Developed downstream from ECMWF's IFS
  - cycle 36r1 made operational by ECMWF in Jan 2010
- Météo France release LAM version
  - Cycle 36t1 made available to HIRLAM in Jan 2010
- HIRLAM staff implement within Harmonie framework
  - Cycle 36h1.1 available to HIRLAM NMSs Jul 2010
- Met Éireann implement operationally
  - Cycle 36h1.3 following testing and evaluation Jul 2011

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Local Implementation

Operational weather models

- "Main" HIRLAM 54h forecast
  - 4DVAR, 54h forecast, 0.1° grid 60 levels
  - 00, 06, 12, 18
- "Hourly" HIRLAM 6h forecast (x24)
  - 3DVAR, 6h forecast, 0.15° grid 60 levels
  - Every hour
- "Ireland25" Harmonie 30h forecast (x4)
  - Surface analysis, 30h forecast, 2.5km grid 60 levels
  - 00, 06, 12, 18

Local Harmonie configuration

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"Ireland25" Harmonie

- Surface analysis only
- 30h forecast
- 2.5km horizontal grid
- 60 vertical levels
- Forecasts at 00, 06, 12, 18

Operational suite

- All times UTC
- Main HIRLAM & Harmonie: 00, 06, 12, 18
- Hourly HIRLAM every hour

T+1:15	T+1:30	T+1:45	T+2:00	T+2:15	T+2:30	T+2:45	T+3:00	T+3:15	T+3:30	T+3:45	T+4:00	T+4:15	T+4:30	T+4:45
	Rerun		HIRLAM Main											
						Harmonie								
Hourly				Hourly				Hourly				Hourly		

Resources &Timeliness

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- HIRLAM must "*wait*" for observations
- Harmonie must wait for HIRLAM to finish
- Harmonie output must delivered by T+4:00
  - eg 12z output must be available at 16z UTC
- This leaves about 1h15m for Harmonie forecast
- Time-step limited to 60s by grid-spacing of 2.5km

Eulerian Dynamics

- Courant-Friedrichs-Levy (CFL) stability criterion:

$$\sigma = c\frac{\delta t}{\delta x} \leq 1$$

- Harmonie: δx=2.5 km, c=300m/s (acoustic waves)

$$\delta t \leq \frac{\delta x}{c}$$
$$\delta t \leq \frac{2500}{300}$$
$$\delta t \leq 8s$$

Semi Lagrangian Dynamics

- Stable tests using CFL numbers ≈ 10

- Thus, δt = 60s used

Domain:540x500

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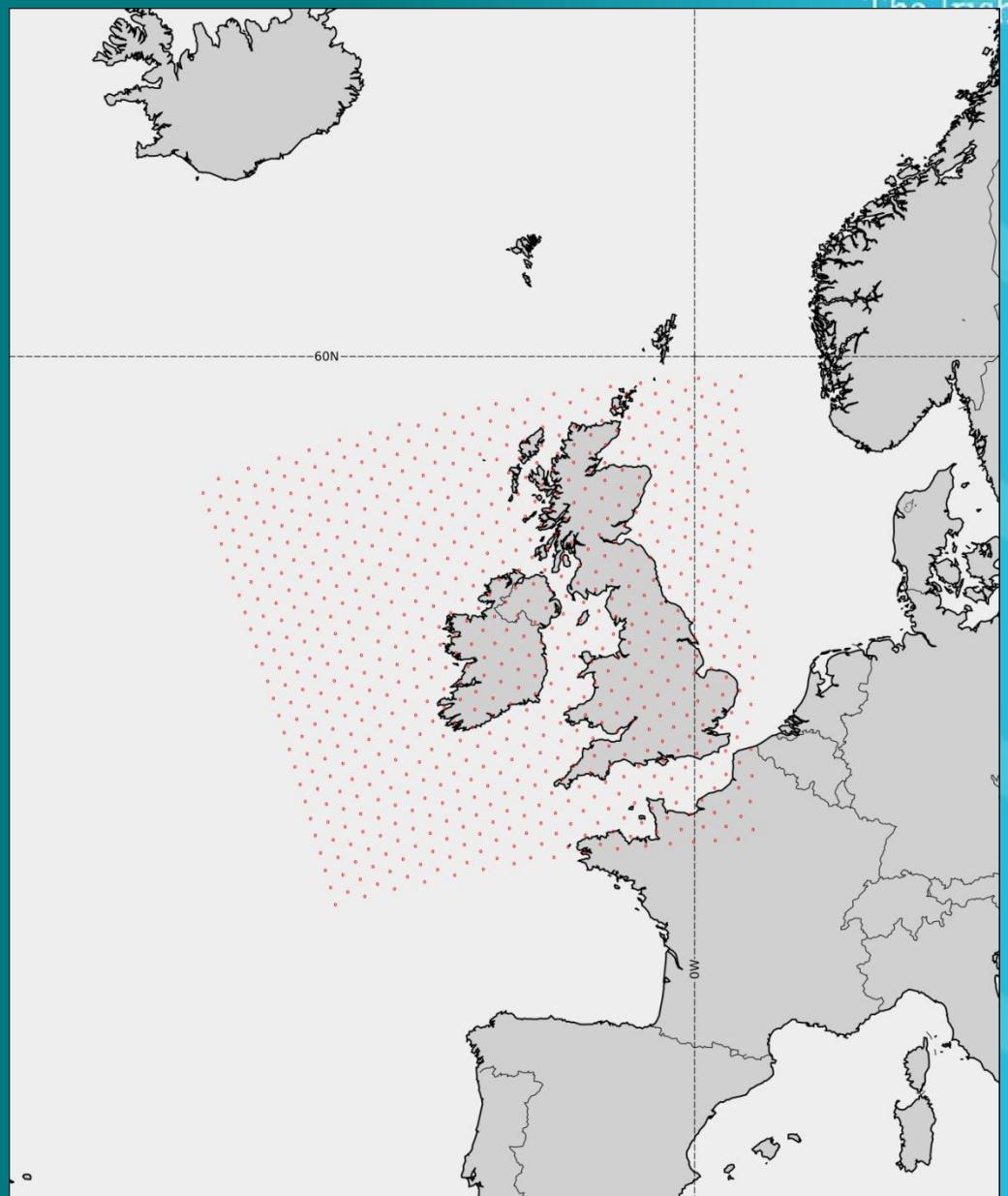
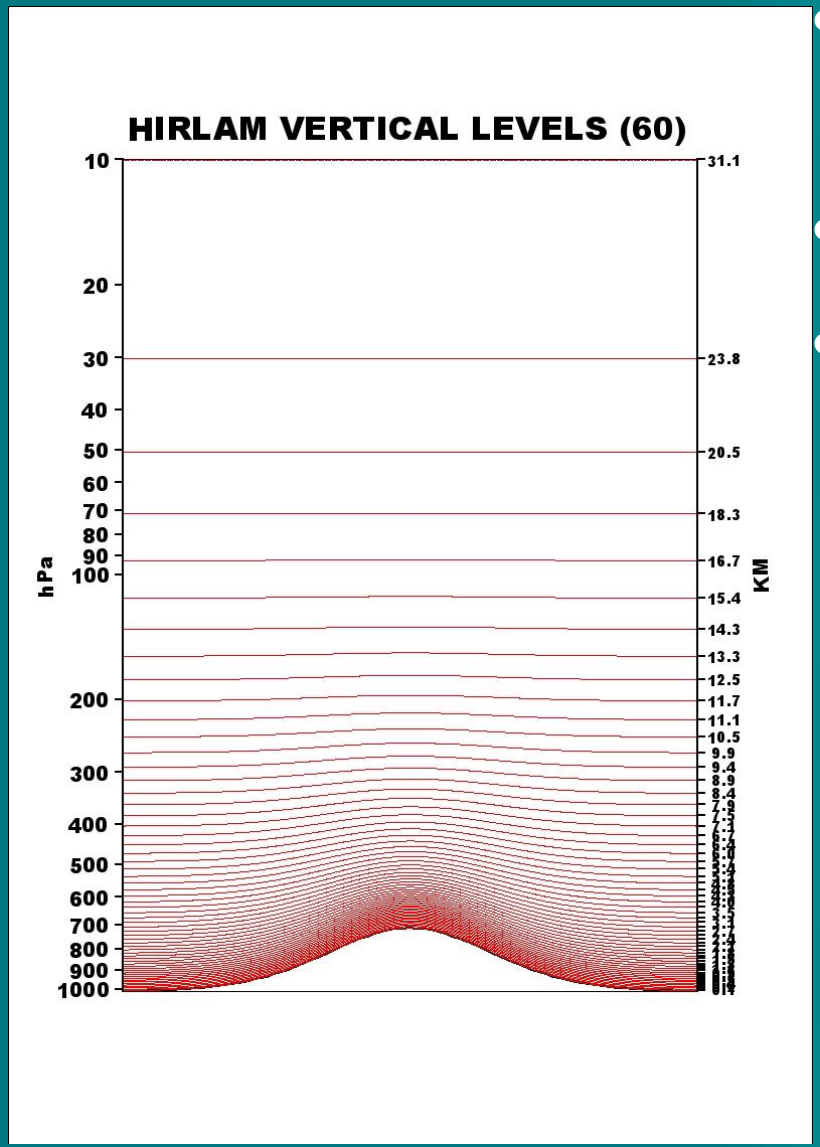


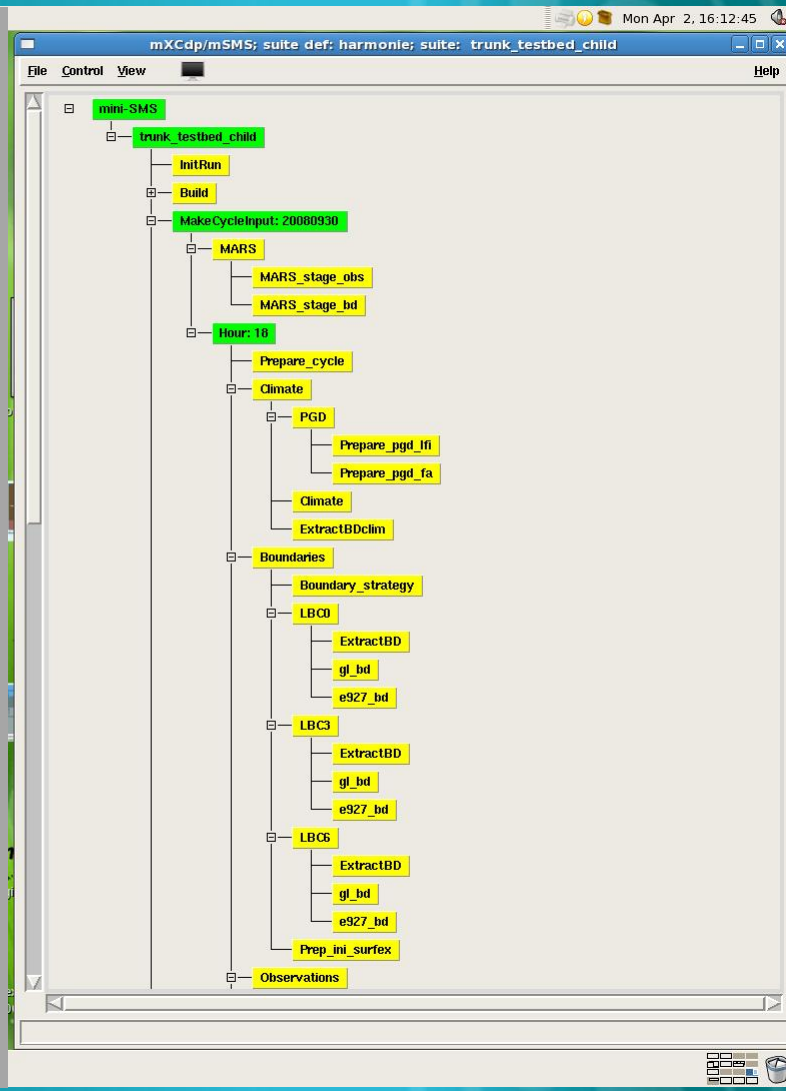
Model Levels



- Top of atmosphere at 10hPa
- First level at 30m
- Levels are "*terrain following*" eta levels

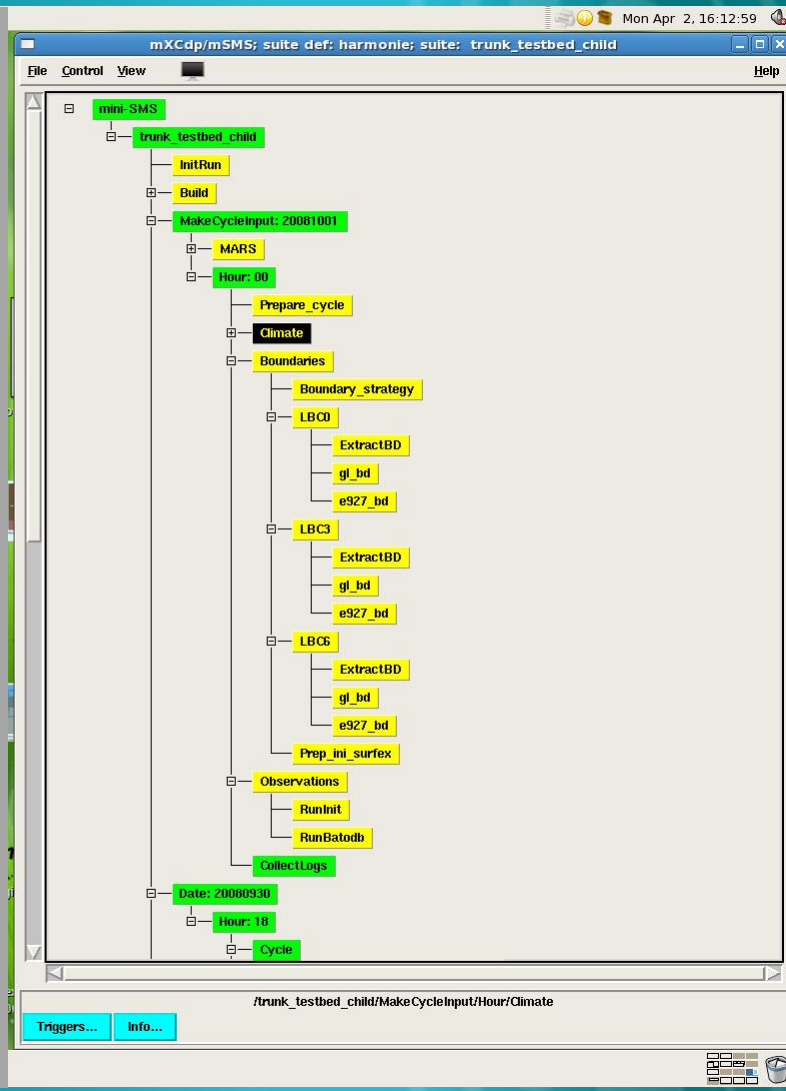
Forecast Components

- Executables compiled
- Climate information generated

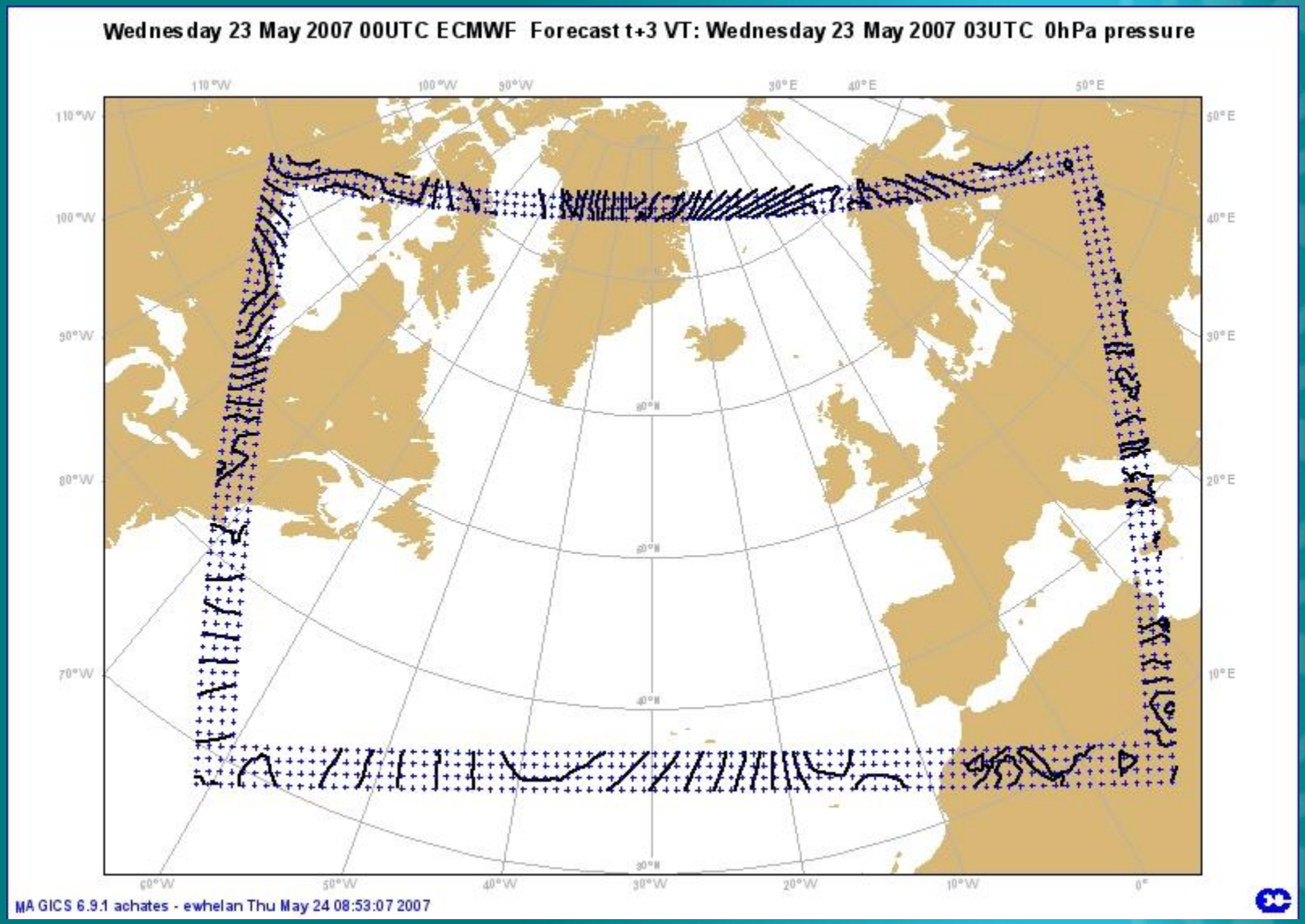


Forecast Components

- Boundary files prepared
- Observations prepared



Lateral boundary conditions



Observations

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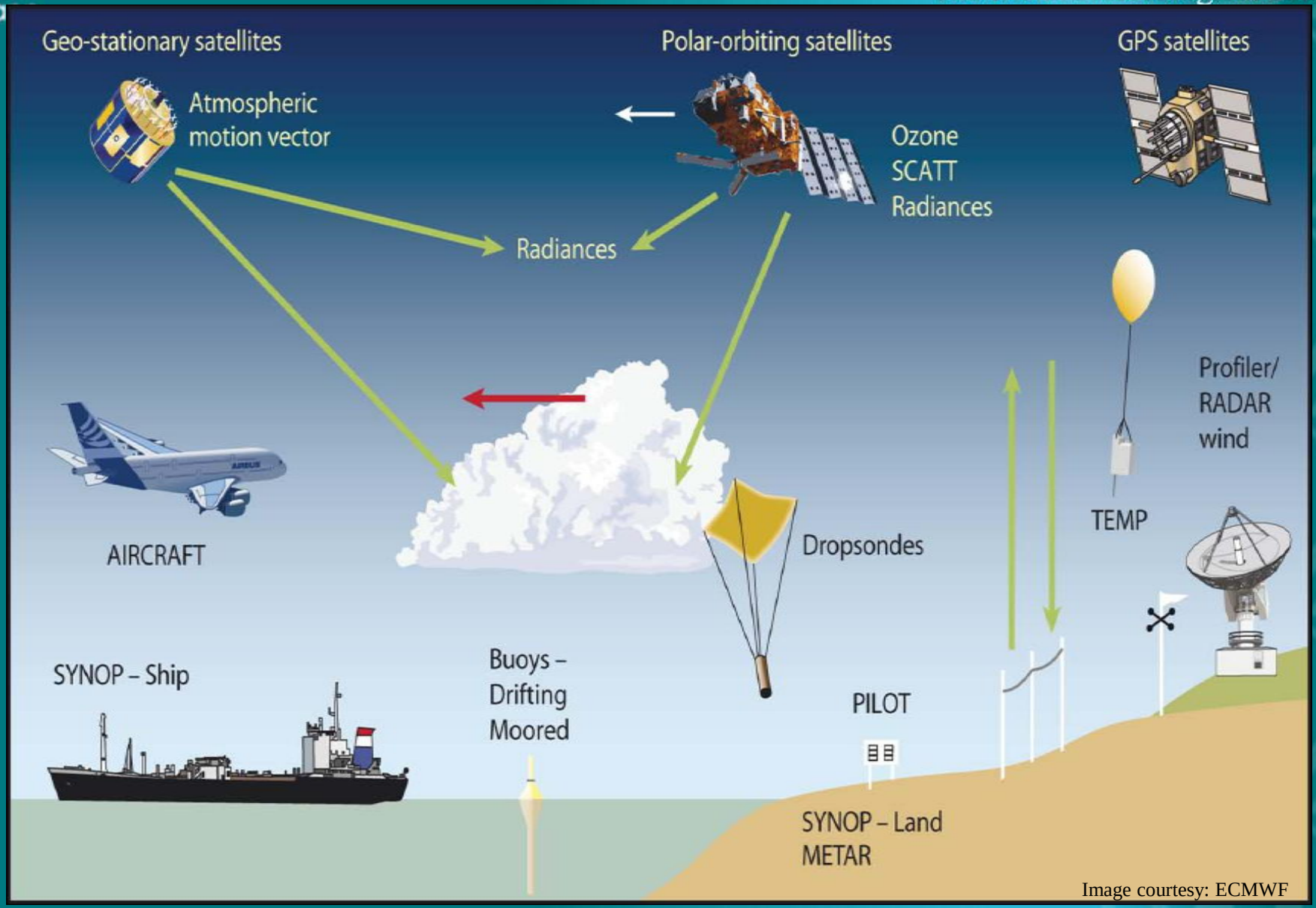

Image courtesy: ECMWF

Observations - Availability

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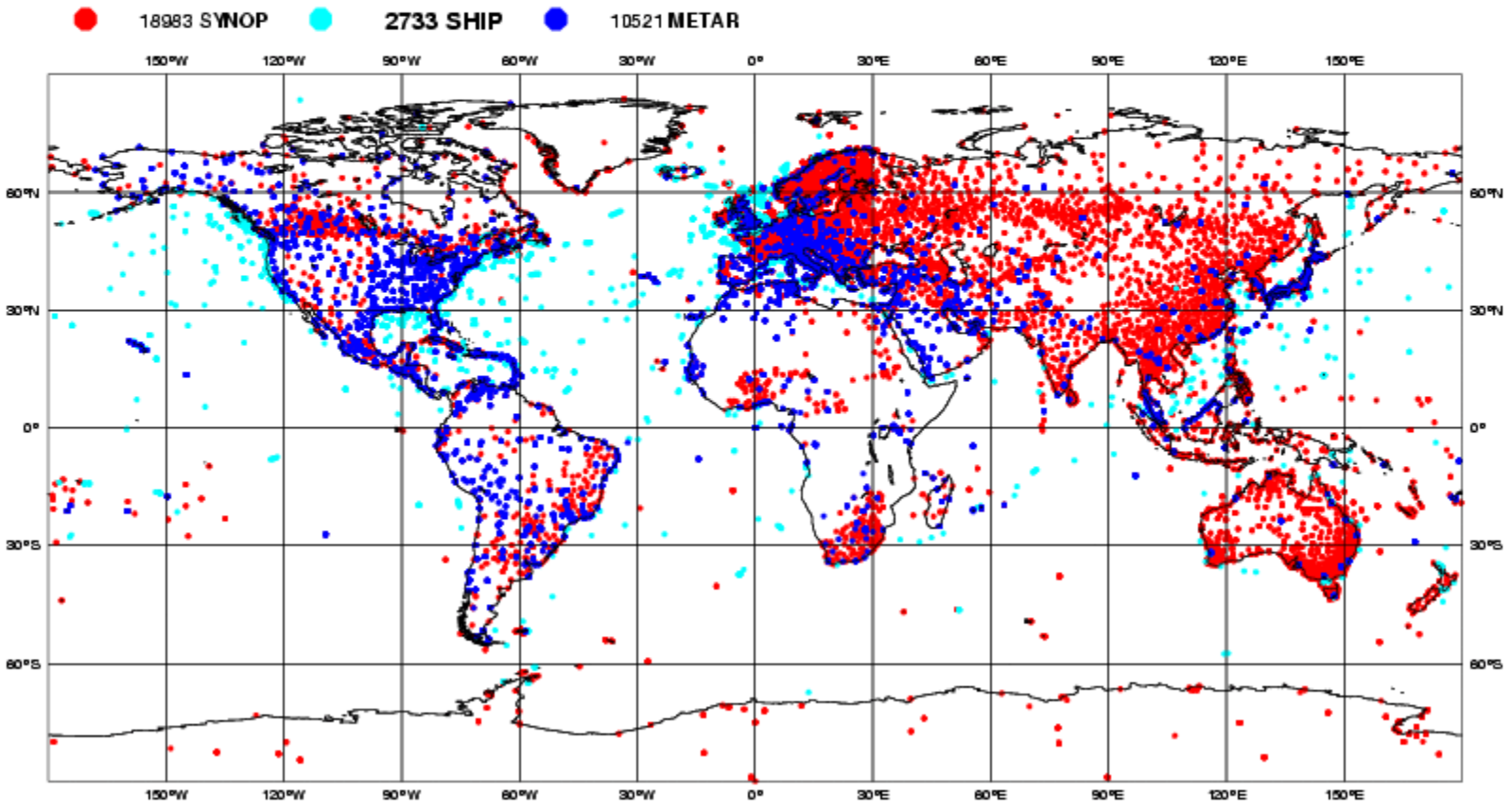
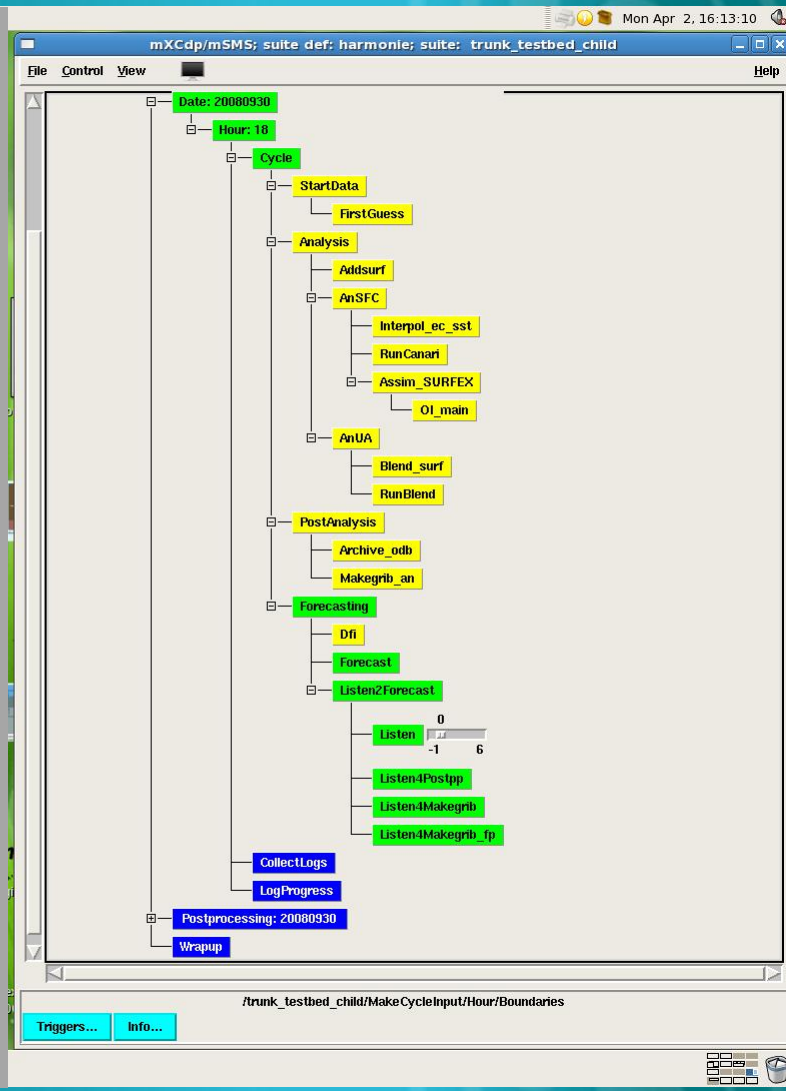
ECMWF Data Coverage (All obs DA) - Synop-Ship-Metar
23/Mar/2012; 00 UTC
Total number of obs = 32237



Forecast Components

- First guess retrieved
- Surface Analysis run
- Upper-air Analysis run
- Digital Filter
- Forecast model run



Data assimilation

- Model first guess
  - short range forecast from previous cycle
- Observations
- Model, observations weighted by their statistical errors are used to formulate a *cost function*, J
- J represents the misfit between the observations, model first guess and the analysis
- J is minimised to produce the “best-fit” state of the atmosphere

Simple example ...

- Two temperature observations, T_1 and T_2
- Error variances of σ_1 and σ_2
- Analyse temperature using two observations

$$J(T) = \frac{1}{2}\left[\frac{(T-T_1)^2}{\sigma_1^2} + \frac{(T-T_2)^2}{\sigma_2^2}\right]$$

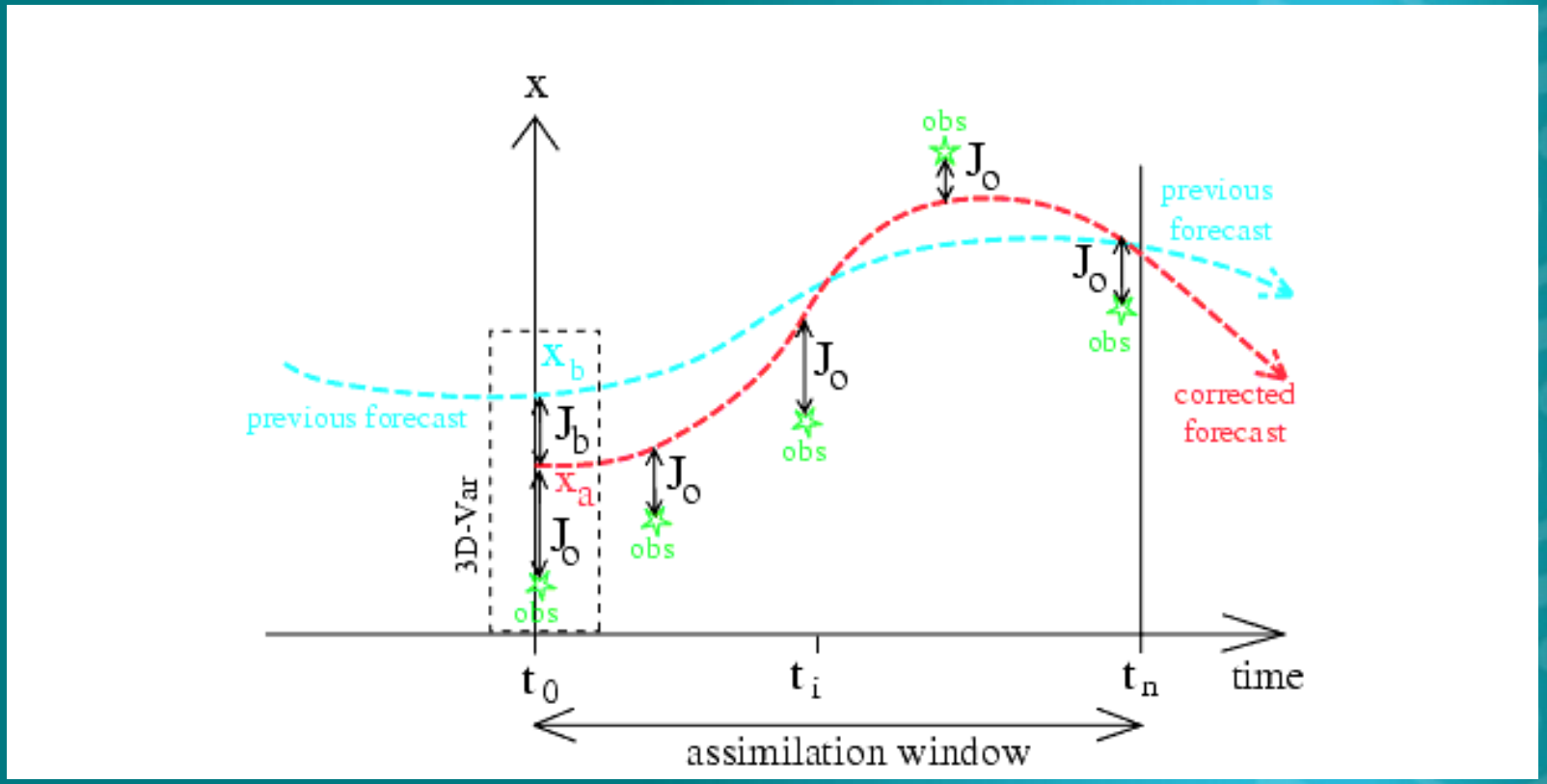
- Minimum of J is solution of $\partial J/\partial T=0$

$$T = \left(\frac{\sigma_2^2}{\sigma_1^2+\sigma_2^2}\right)T_1 + \left(\frac{\sigma_1^2}{\sigma_1^2+\sigma_2^2}\right)T_2$$

- Observation with smaller error variance is given greater weight

Not so simple ...

- 4DVAR: 4-D Variational Data Assimilation
- 3DVAR: 3-D Variational Data Assimilation



$$J(\mathbf{x}) = \tfrac{1}{2}(\mathbf{x}-\mathbf{x}_b)^T \mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_b) + (\mathbf{y}_m - H(\mathbf{x}))^T \mathbf{R}^{-1}(\mathbf{y}_m - H(\mathbf{x}))$$

Harmonie Forecast model

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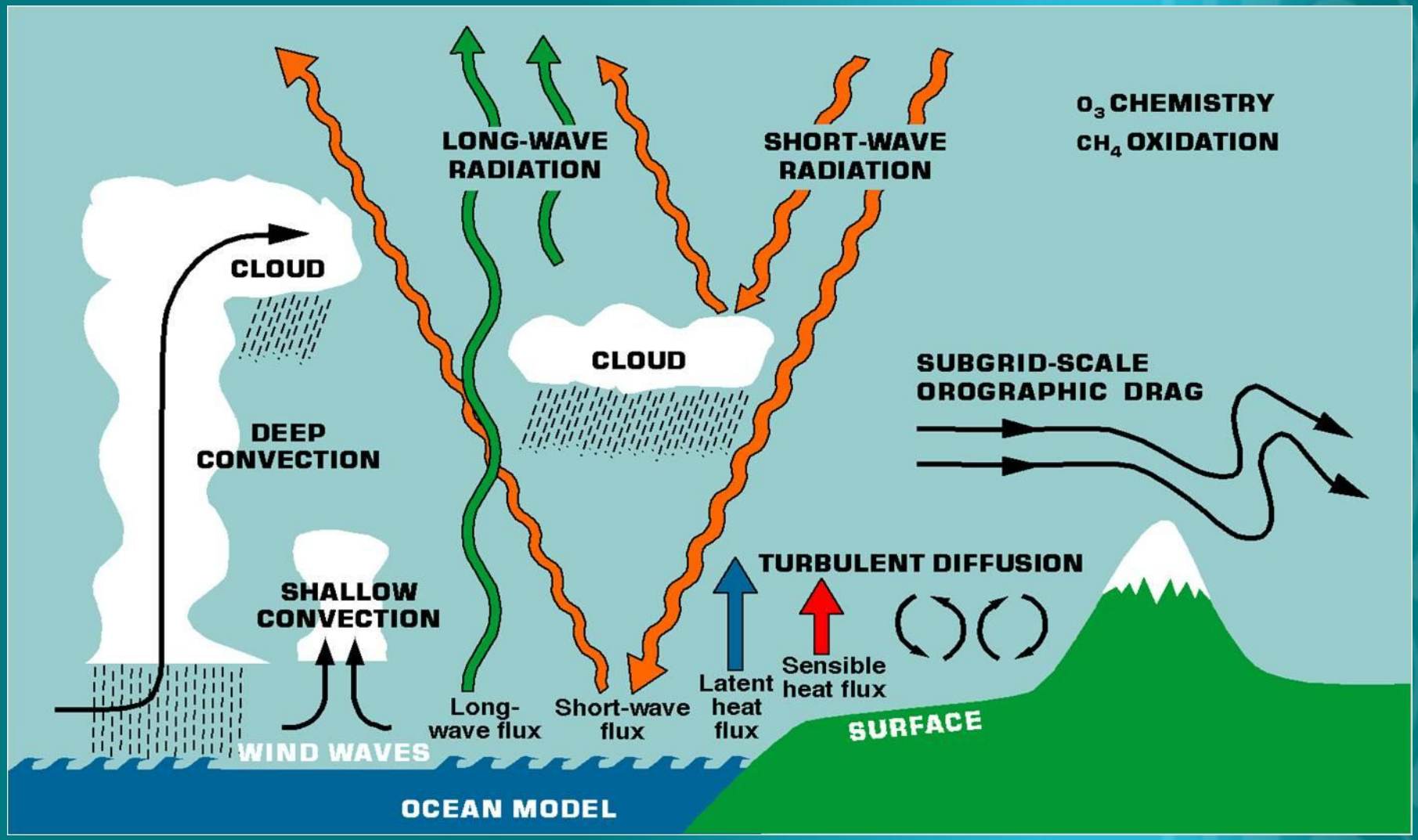
Non-hydrostatic, spectral limited area mesoscale model

- Non-hydrostatic: entire vertical momentum equation used in the primitive equations.
  - Hydrostatic approximation not used $\frac{1}{\rho}\frac{\partial p}{\partial z} \approx -g$ (buoyancy balanced by gravity)
- Spectral: Variables not stored on regular grid but represented by wave functions of differing wavelengths
- Limited area: Forecast calculations carried out on a limited area of the globe
- Mesoscale: kilometre scale processes resolved – deep convection, squall lines, sea breezes

Parameterization

- Model resolution limited by computing resources
  - Clouds
  - Turbulent eddies
- Model cannot “see” these things
- Parameterizations are used to simulate the large-scale feedback that small scale features produce
  - For example: an “average” cloudiness over a grid box

Parameterization



Sample forecast

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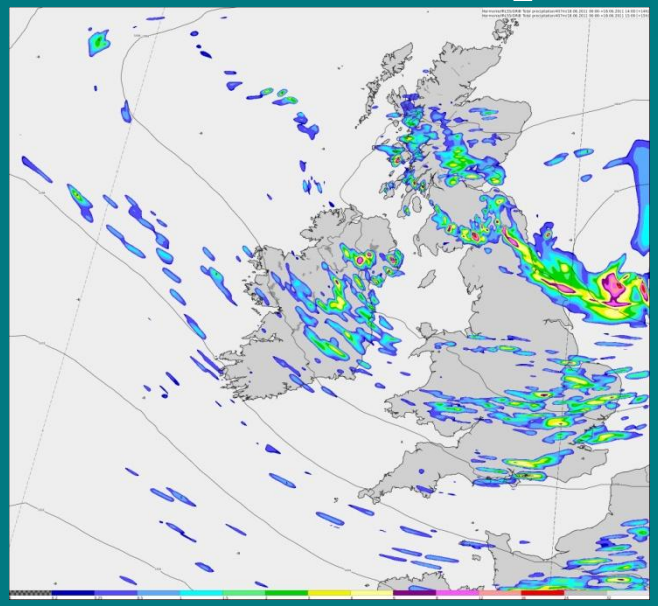
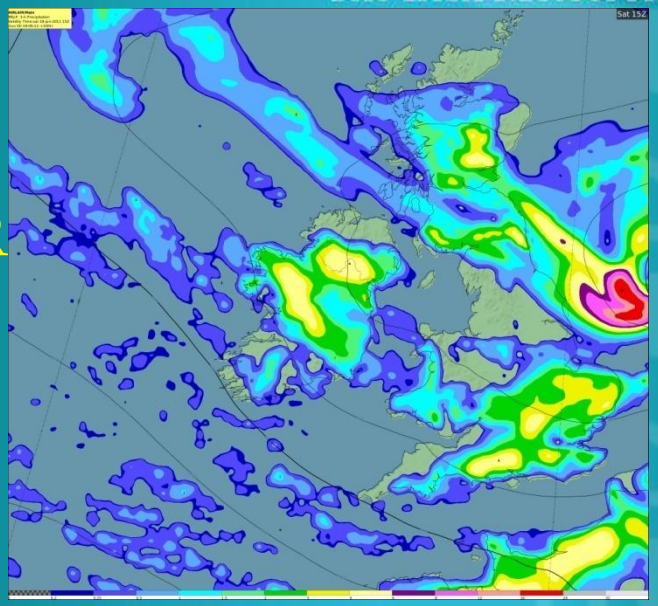
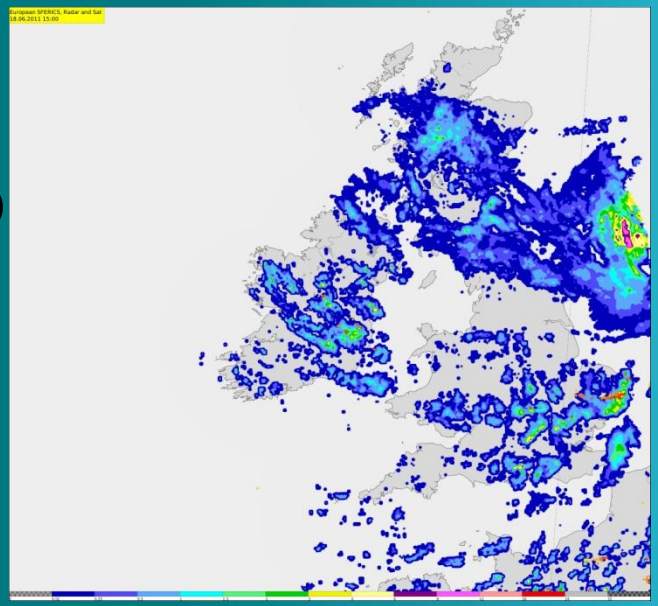
HAR



HIR



RAD



Today's forecast (20120403 00z)

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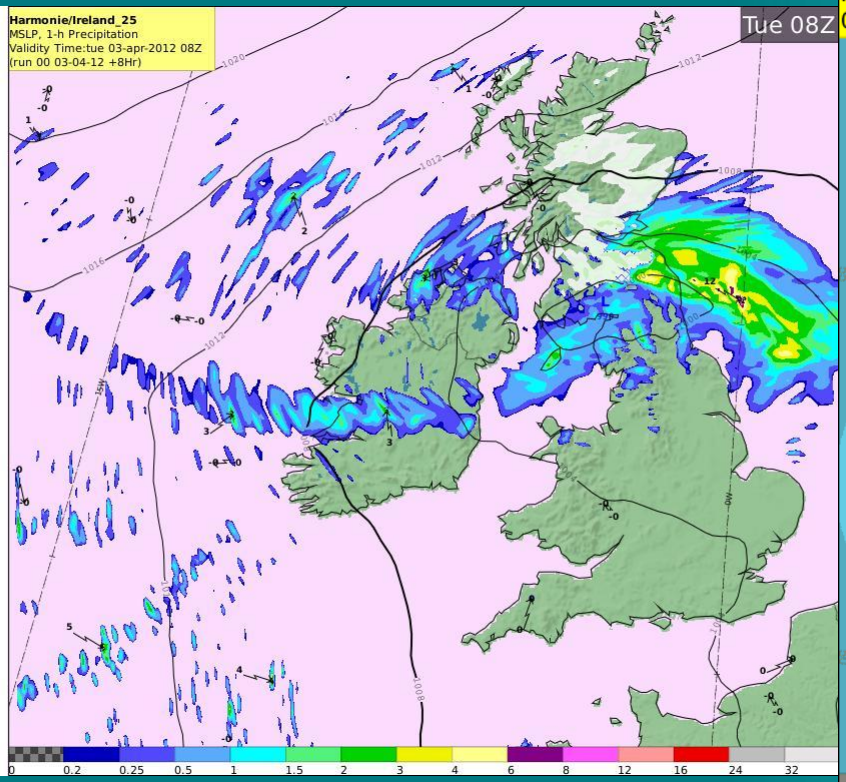

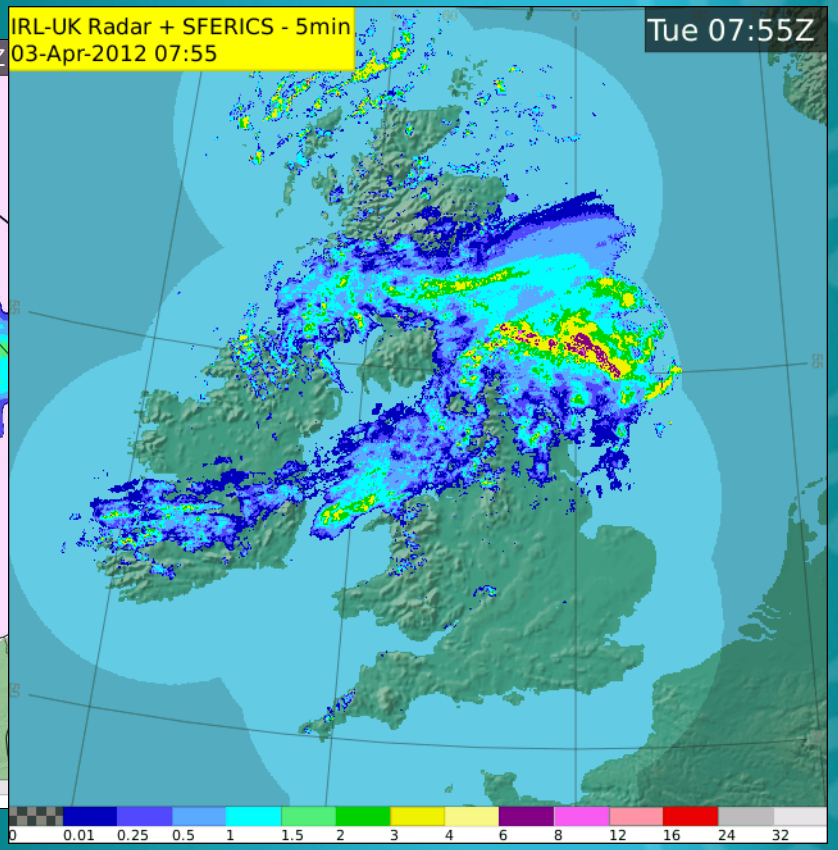

Today's forecast (20120403 00z)

End users of NWP data

- Met Éireann forecasters
- Roadice forecasts
- Web products
- RPII
- Commercial Customers

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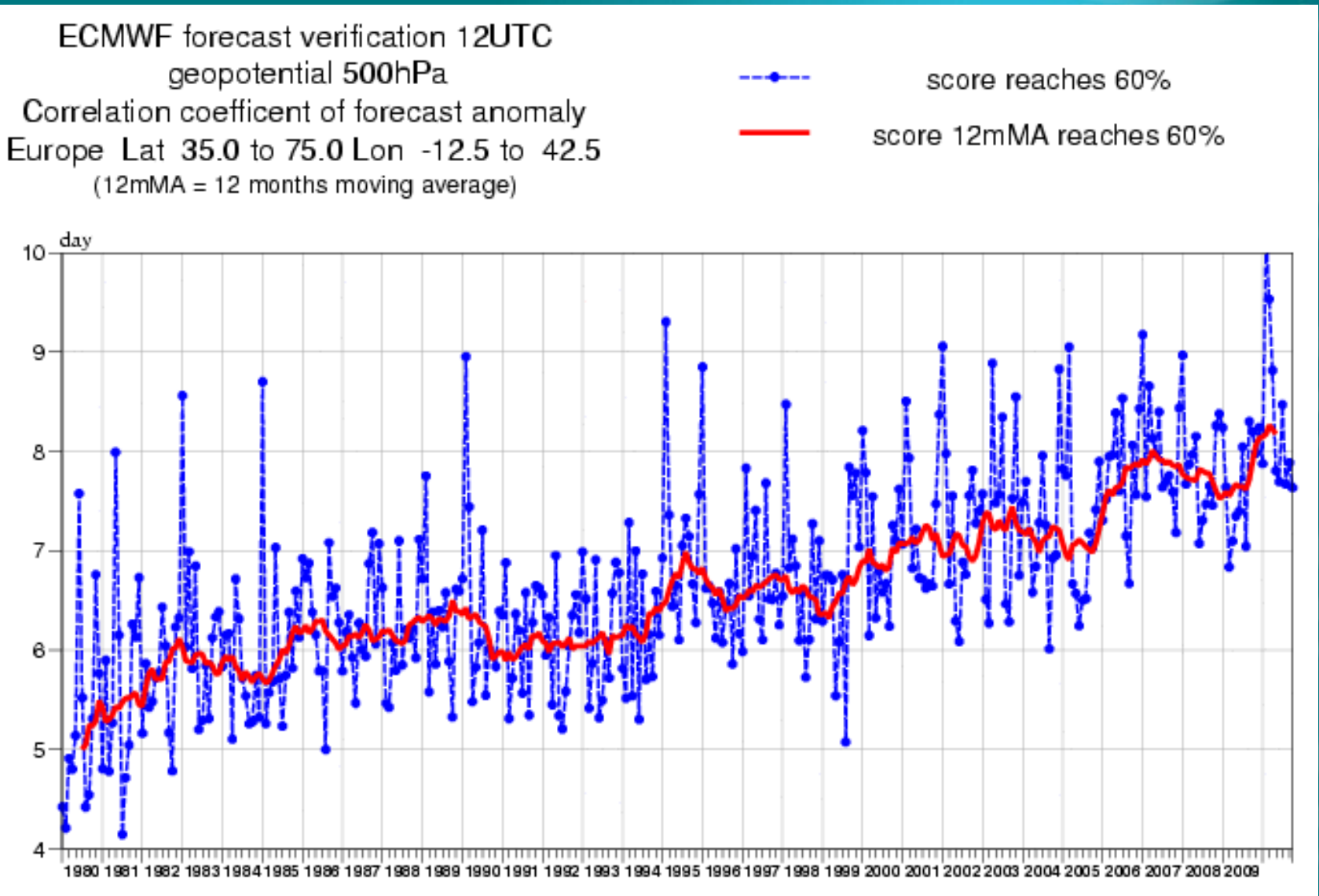
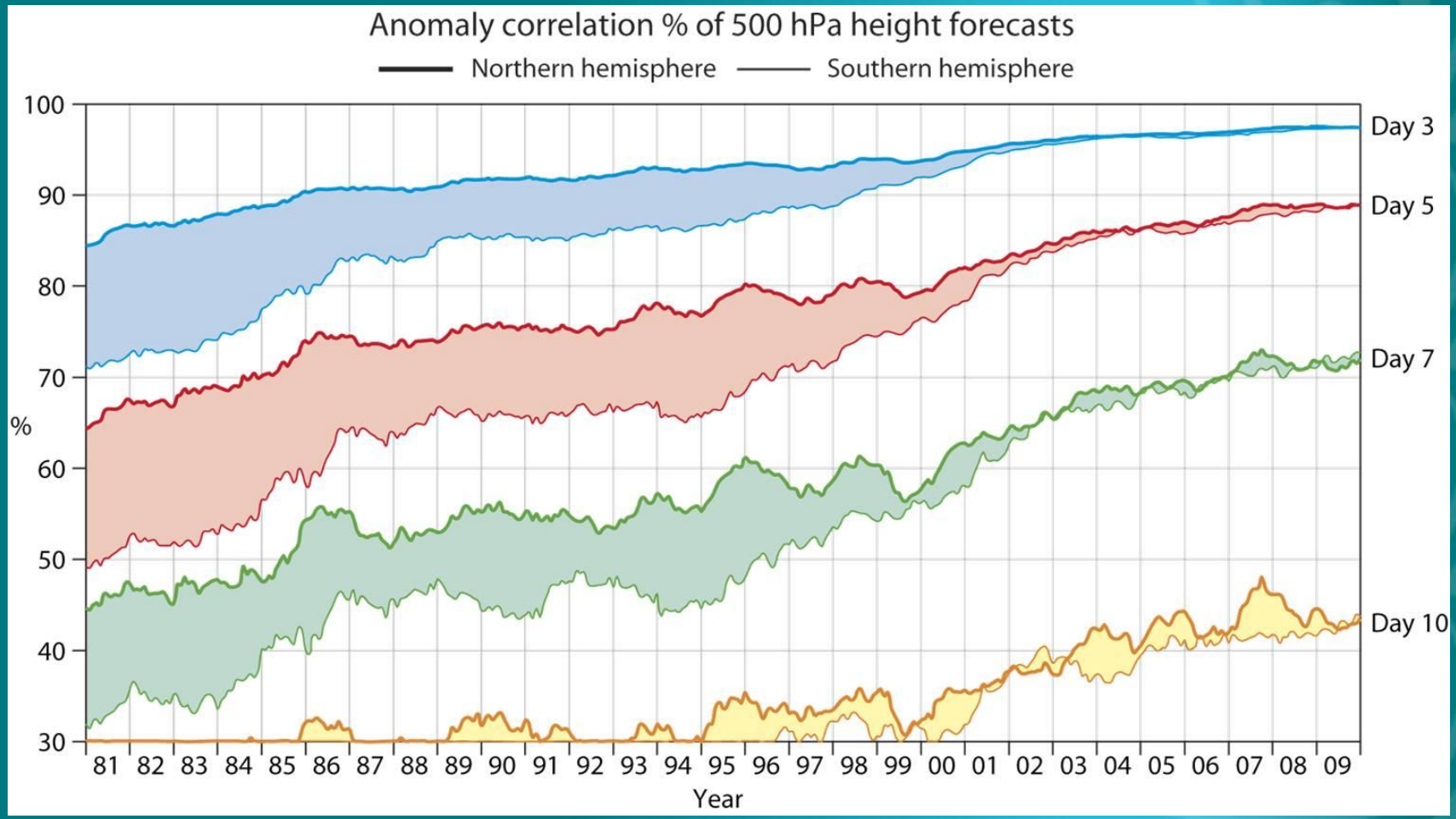
Verification

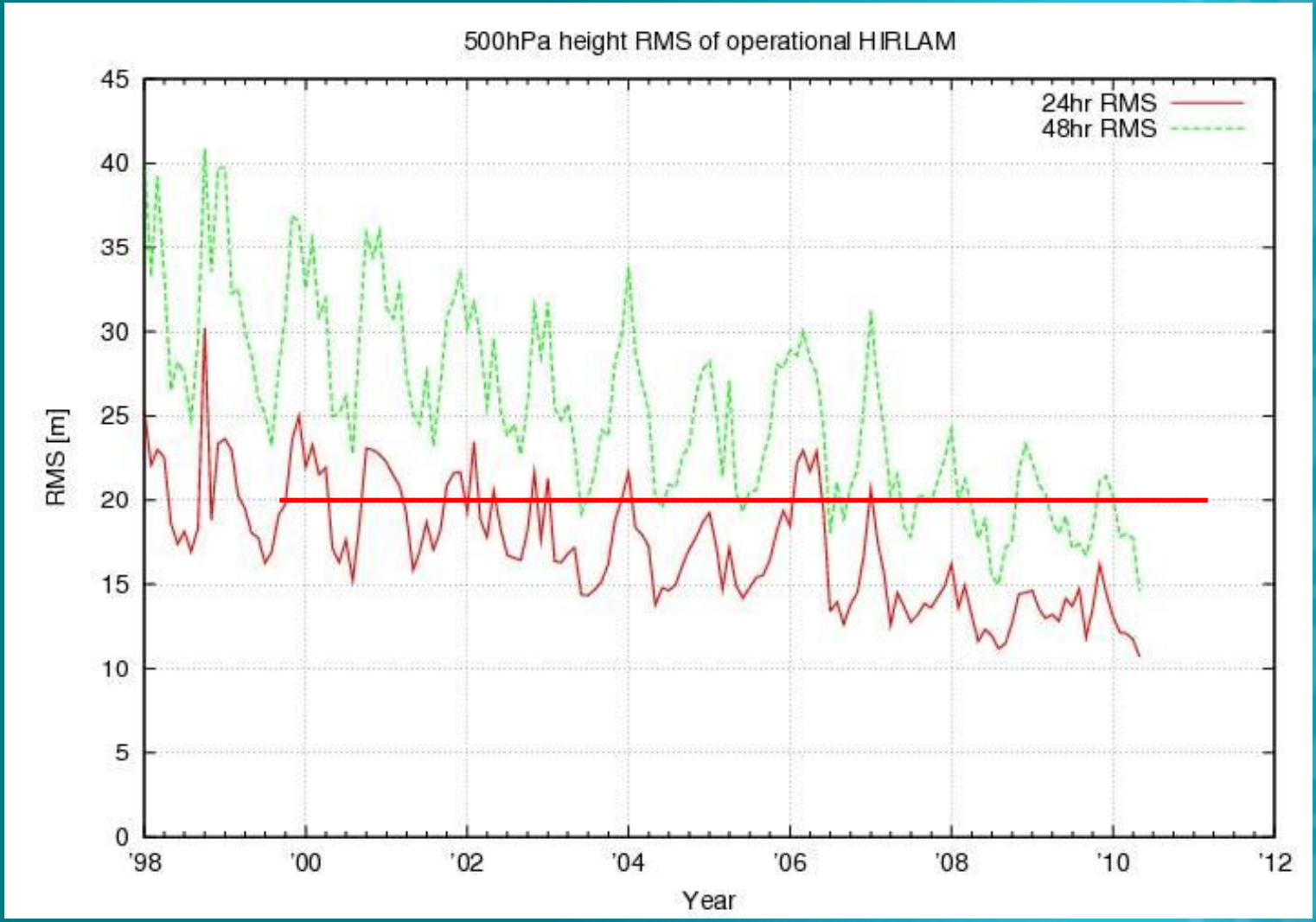
ECMWF: historical



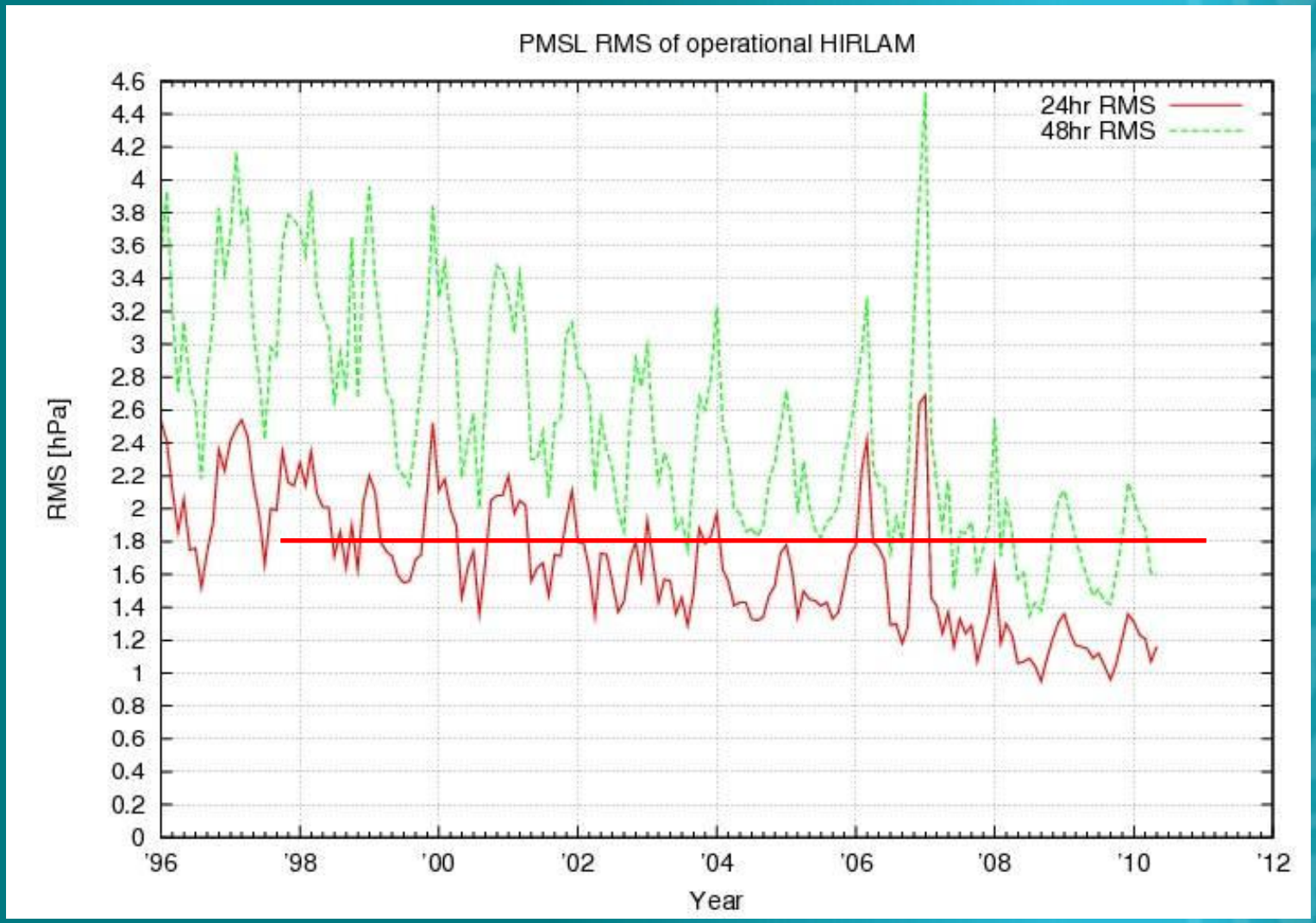
ECMWF: historical



HIRLAM: historical



HIRLAM: historical



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Development Work

Development work at Met Éireann

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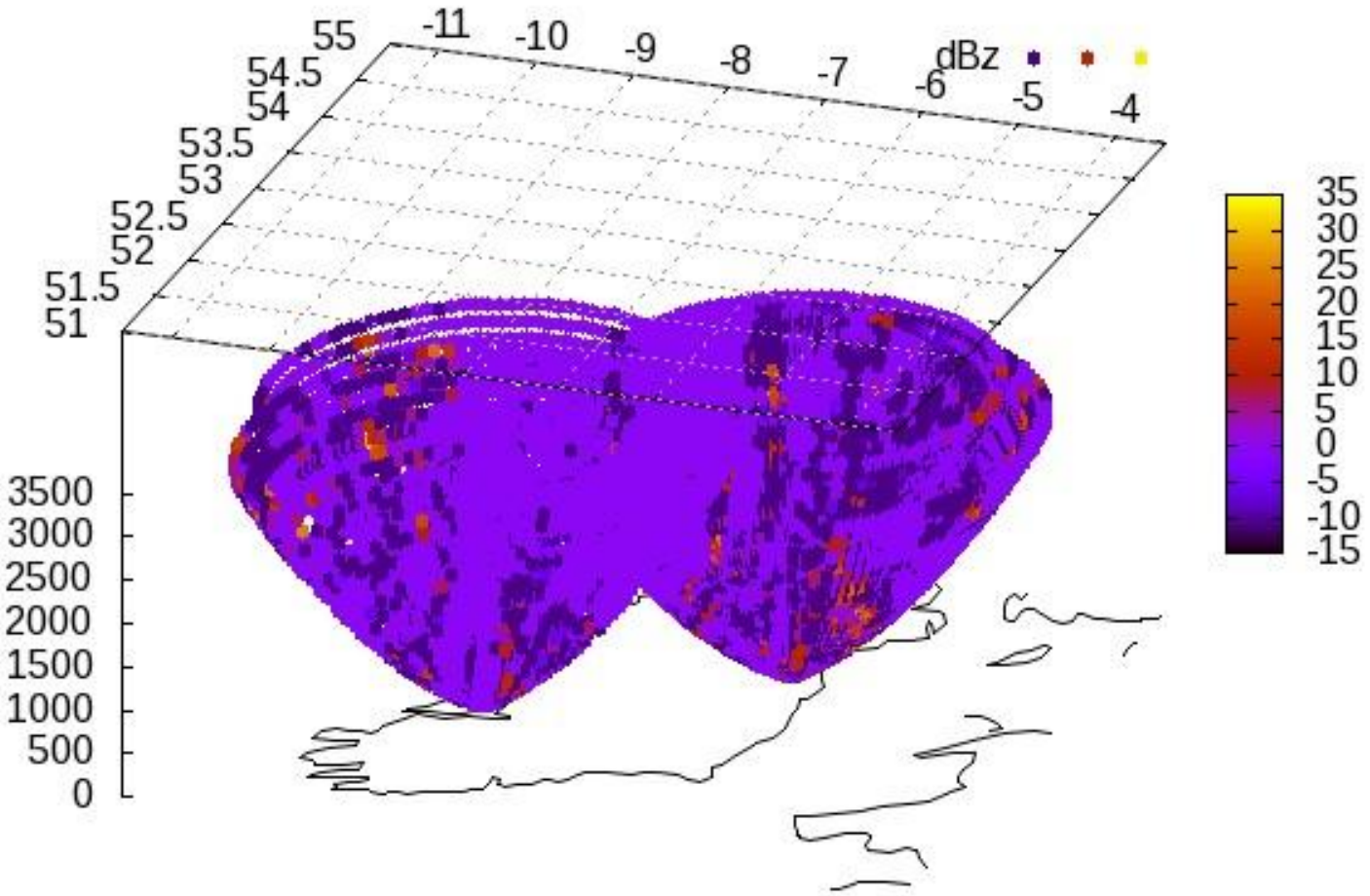
- Surface processes
- Radiation
- **Use of Observations**

Radar data


55
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2500
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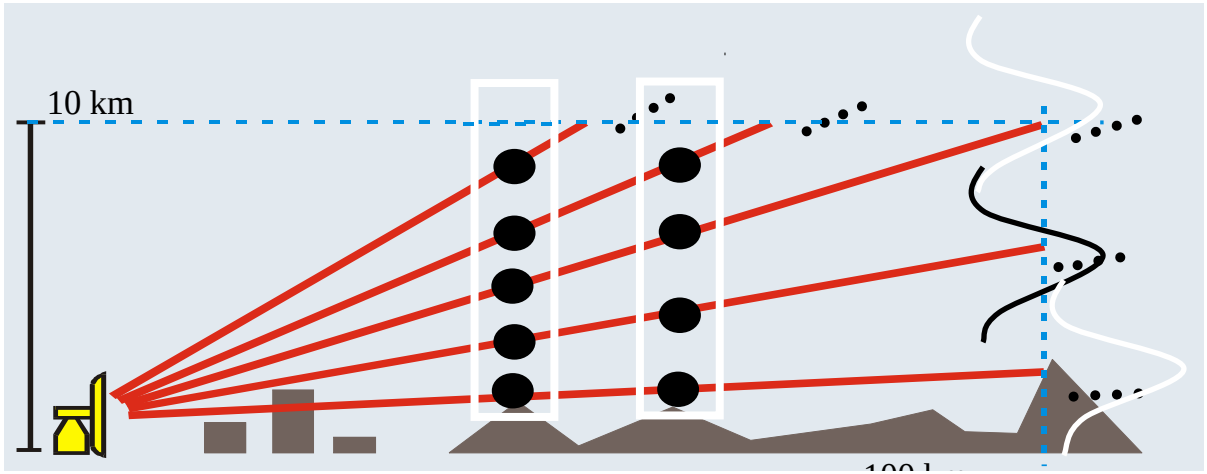
-15

Radar product for AROME… in the model



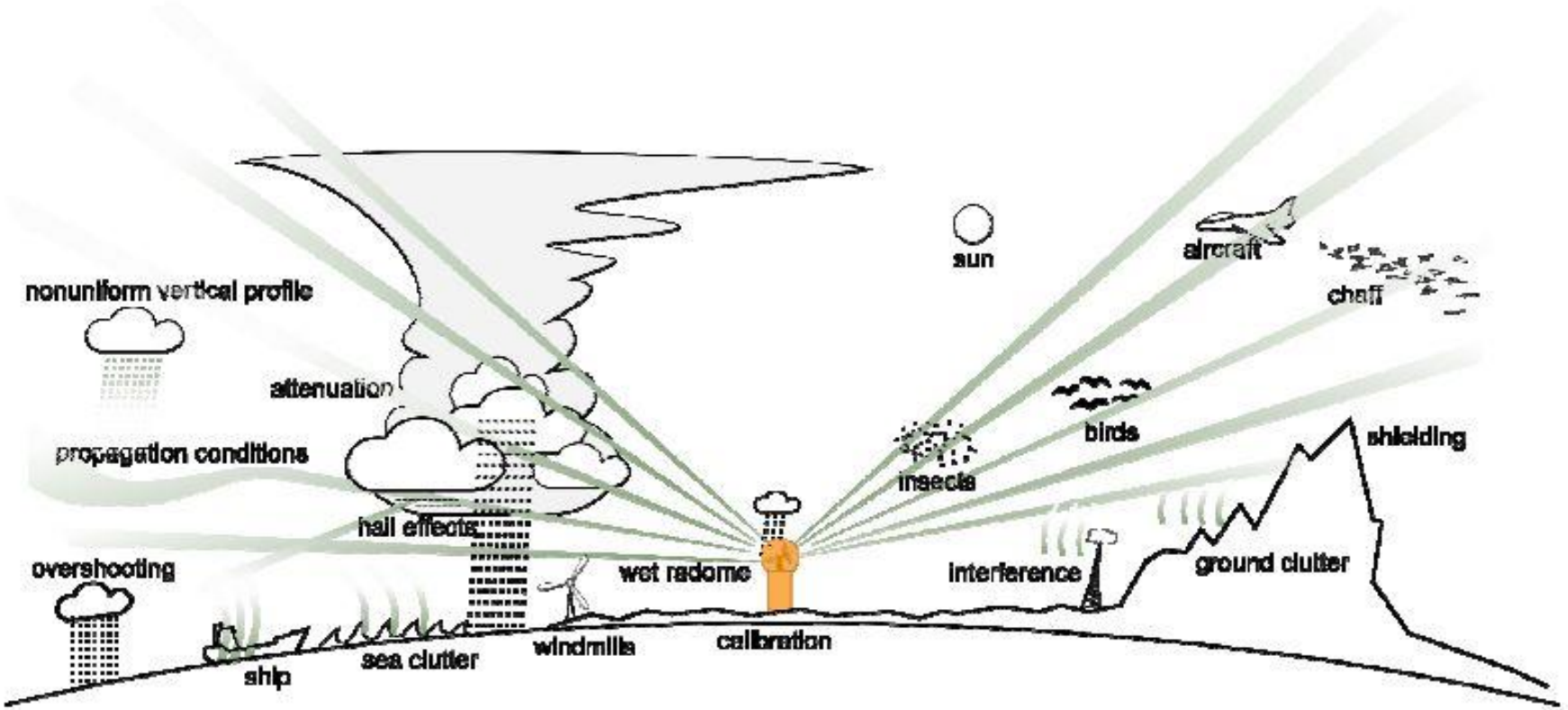
If ONLY ONE pixel is rainy on the column either in the model OR in the radar then

COMPUTING OF A HUMIDITY RETRIEVAL

Using columns of observations in model

- *Radar observations considered as profiles in the model*
- *Altitudes of the pixels calculated considering* ***a constant refractivity index along the ray path (i.e using the approximation of the Earth's effective radius: consistency with observation operator****, see hereafter)*
- *This last approximation is also consistent with the* ***non-horizontal integration of the beam*** *because of parallel purposes of the code (we cannot simulate anomalous propagation and attenuation!!)*

Quality challenges



Thanks: M. Peura (FMI)

High-resolution radiosonde data

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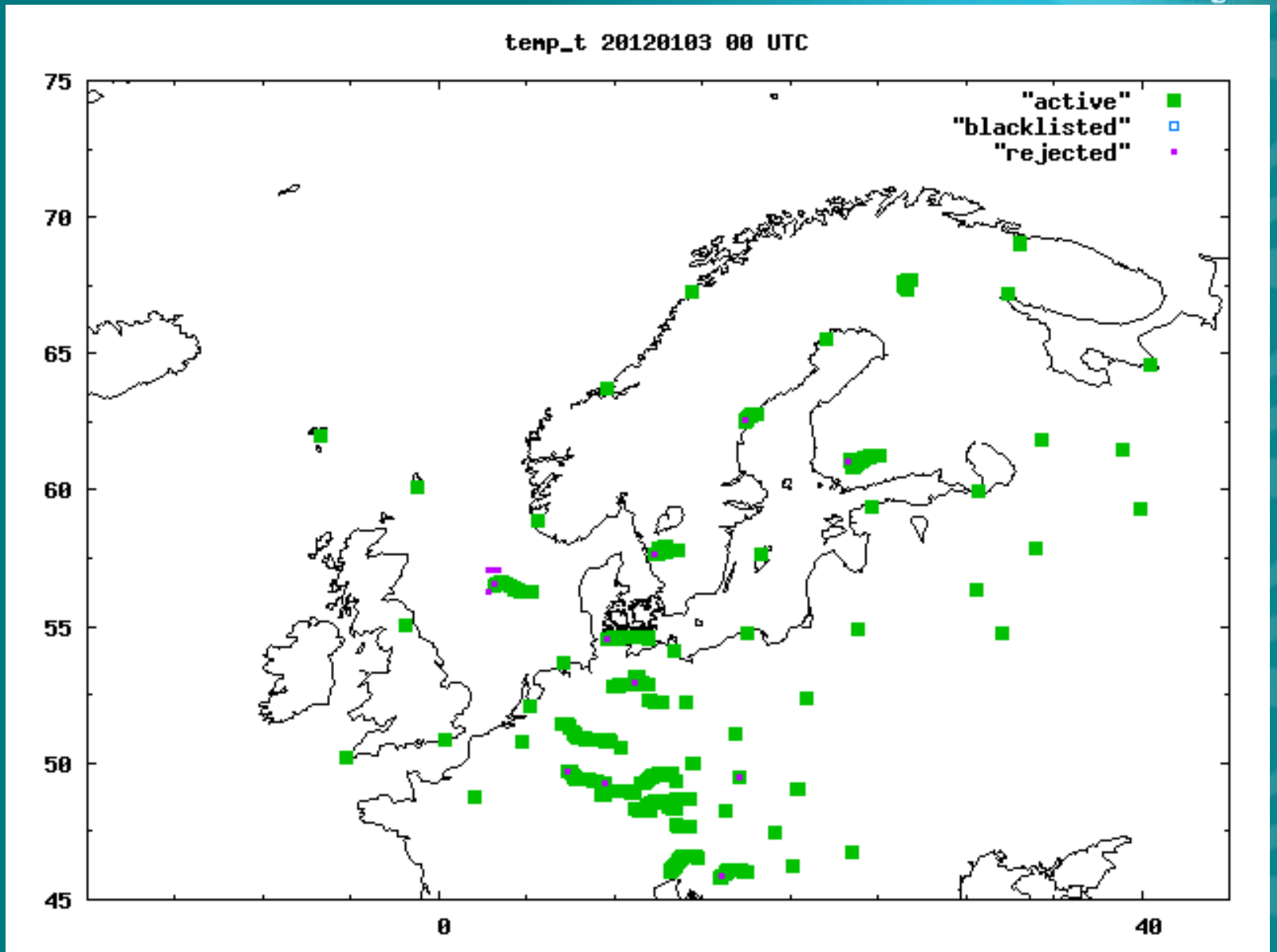

High-resolution radiosonde data

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Thank you for your attention!
Questions?

Operational HIRLAM details:

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- *Analysis* : Hirlam 3/4D-Var [3/4-dimensional variational assimilation]. The analysis runs on 60 hybrid [eta] levels. Upper-air observational data is accepted on all standard and significant levels (10 hPa to 1000 hPa) and interpolated to eta levels.
- *Assimilation Cycle* : Three-hour cycle using the forecast from the previous cycle as a first-guess. [It is also possible to use an ECMWF forecast as a first-guess].
- *Initialisation* : Digital Filter
- *Forecast Model* : Hirlam 7.2reference system grid point model. This is hydrostatic model and it is run on a rotated latitude-longitude grid with the South-Pole at (-30° longitude, -30° latitude). Fields are based on a 438x284 grid corresponding to a 0.10° x 0.10° horizontal Arakara C-grid. There are 60 levels in the vertical.
- *Integration Scheme* : We use a two time-level three-dimensional semi-Lagrangian semi-implicit scheme with a time-step of 300 seconds.
- *Filtering* : Fourth order implicit horizontal diffusion.
- *Physics* : CBR vertical diffusion scheme; Sundqvist condensation scheme with the 'STRACO' (Soft TRAnsition COndensation scheme) cloud scheme; Savijarvi radiation scheme.
- *Lateral Boundary Treatment* : Davies-Kallberg relaxation scheme using a cosine dependent relaxation function over a boundary zone of 8-lines. The latest available ECMWF 'frame' files are used [based on 4 ECMWF runs per day at 00Z, 06Z, 12Z and 18Z,

Harmonie details:

- The HARMONIE model is a non-hydrostatic spectral model, of which the dynamical core (developed by ALADIN) is based on a two-time level semi-implicit Semi-Lagrangian discretisation of the fully elastic equations, using a hybrid coordinate in the vertical. Optionally, for larger domains and coarser resolutions the hydrostatic version of this semi-Lagrangian scheme can be used. An Eulerian dynamics core is available, but has been little used in recent years.
- A variety of sub-gridscale physical processes are taken into account by parametrization schemes. Basically, the parametrizations adopted in HARMONIE are the same as those of the AROME model, developed by the meso-NH community. Extensive scientific documentation is available from the Meso-NH scientific documentation on the upper air physics and on the surface module SURFEX.

Scale analysis

Example :

Typical observed values for mid-latitude synoptic systems:

$U \sim 10\ \mathrm{ms}^{-1}$

$W \sim 10^{-2}\ \mathrm{ms}^{-1}$

$L \sim 10^{6}\ \mathrm{m}$

$\Delta p/\rho L \sim 10^{3}\ \mathrm{m}^{2}\mathrm{s}^{-2}$

$f_0 \sim 10^{-4}\ \mathrm{s}^{-1}$

$a \sim 10^{7}\ \mathrm{m}$

$H \sim 10^{4}\ \mathrm{m}$

$$(\mathrm{f} = 2\Omega \sin\theta)$$

Scale analysis (continued)

$$\frac{du}{dt} = 2\Omega v \sin\theta - 2\Omega w \cos\theta + \frac{uv}{r}\tan\theta - \frac{uw}{r} - \frac{1}{\rho r \cos\theta}\frac{\partial p}{\partial \lambda}$$

$$\frac{dv}{dt} = -2\Omega u \sin\theta - \frac{u^2}{r}\tan\theta - \frac{vw}{r} - \frac{1}{\rho r}\frac{\partial p}{\partial \theta}$$

U^2/L	f_0U	f_0W	U^2/a	UW/a	$\Delta p/\rho L$
10^{-4}	10^{-3}	10^{-6}	10^{-5}	10^{-8}	10^{-3}

$$\frac{dw}{dt} = 2\Omega u \cos\theta + \frac{u^2 + v^2}{r} - \frac{1}{\rho}\frac{\partial p}{\partial r} - g$$

UW/L	f_0U	U^2/a	$p/\rho H$	g
10^{-7}	10^{-3}	10^{-5}	10	10

Scale analysis (continued)

- Consequences if you want to resolve synoptic motions in the mid-latitudes:
- Assume a shallow atmosphere with radius $r = a + z \sim a$
- Allow to drop Coriolis and metric terms which depend on *w*
- Make the *hydrostatic approximation*

Quasi-Geostrophic balance : accelerations du/dt, dv/dt are "small" differences between two large terms

$$fv \approx \left[\frac{1}{\rho} \frac{\partial p}{\partial x} = fv_g \right] \text{ and } fu \approx \left[-\frac{1}{\rho} \frac{\partial p}{\partial y} = fu_g \right]$$

Hydrostatic balance

$$\frac{1}{\rho}\frac{\partial p}{\partial z} \approx -g$$

- The pressure gives "the weight" of the atmosphere above
- (approx) no background vertical acceleration

Quai-Geostrophic Approx

- Mid-latitude Synoptic systems
- Hydrostatic and nearly geostrophic
  - Geostrophic wind: the theoretical wind that would result from an exact balance between the Coriolis effect and the pressure gradient force
  - Hydrostatic balance: (approx) no background vertical acceleration
- Flow is then approx determined by isobaric distribution of geopotential
- Isobaric co-ord sys used:
  - Met measurements generally on p – levels
  - Dyn equations simpler on p - levels