

ReAnalyses

Overview, background and needs

Different types of reanalyses

Multi models – Ensembles

Use of reanalyses and uncertainties

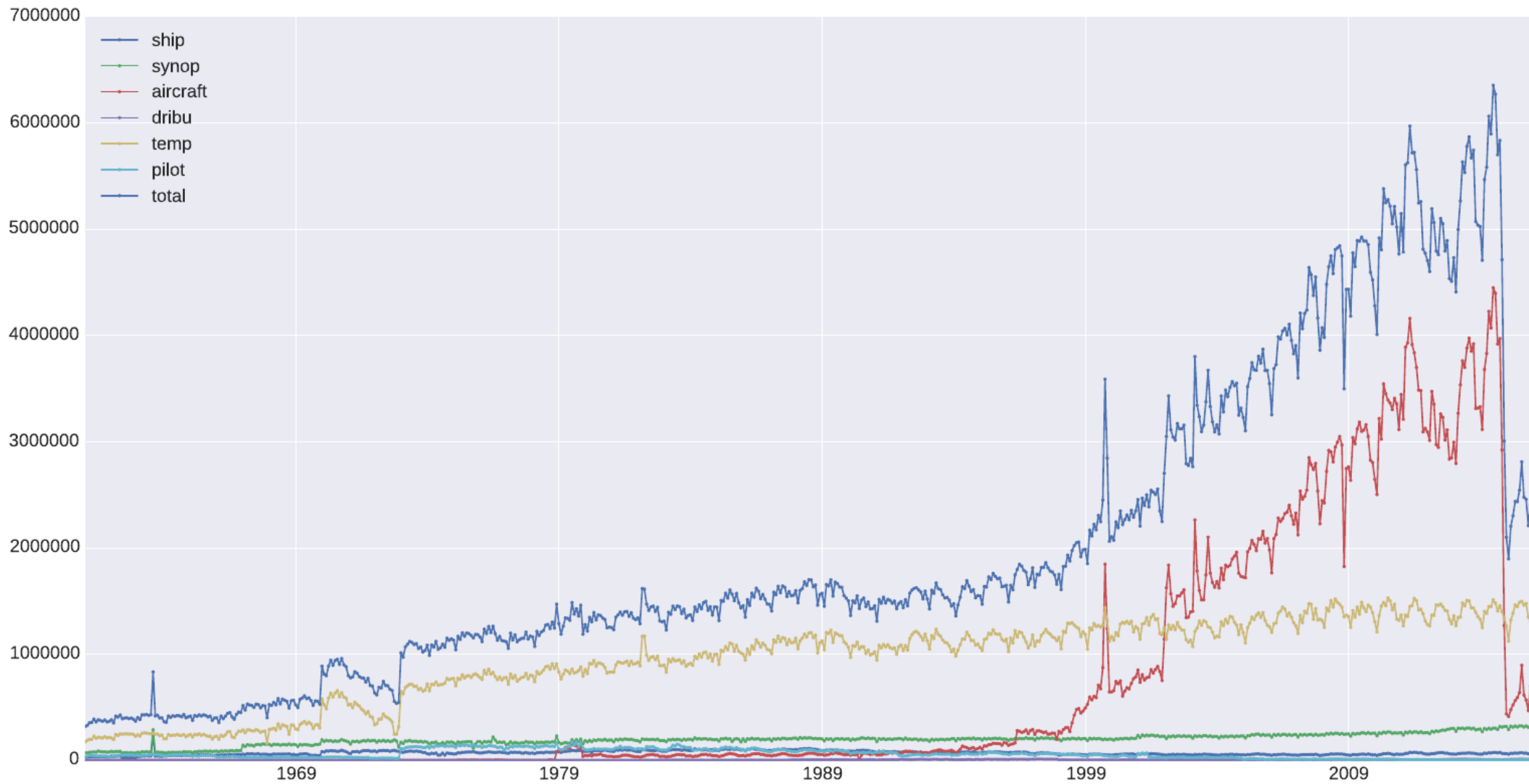
User interaction



Copernicus Climate Change Services (C3S)



All observations 1961-2015 (c.o. Klaus Zimmerman)

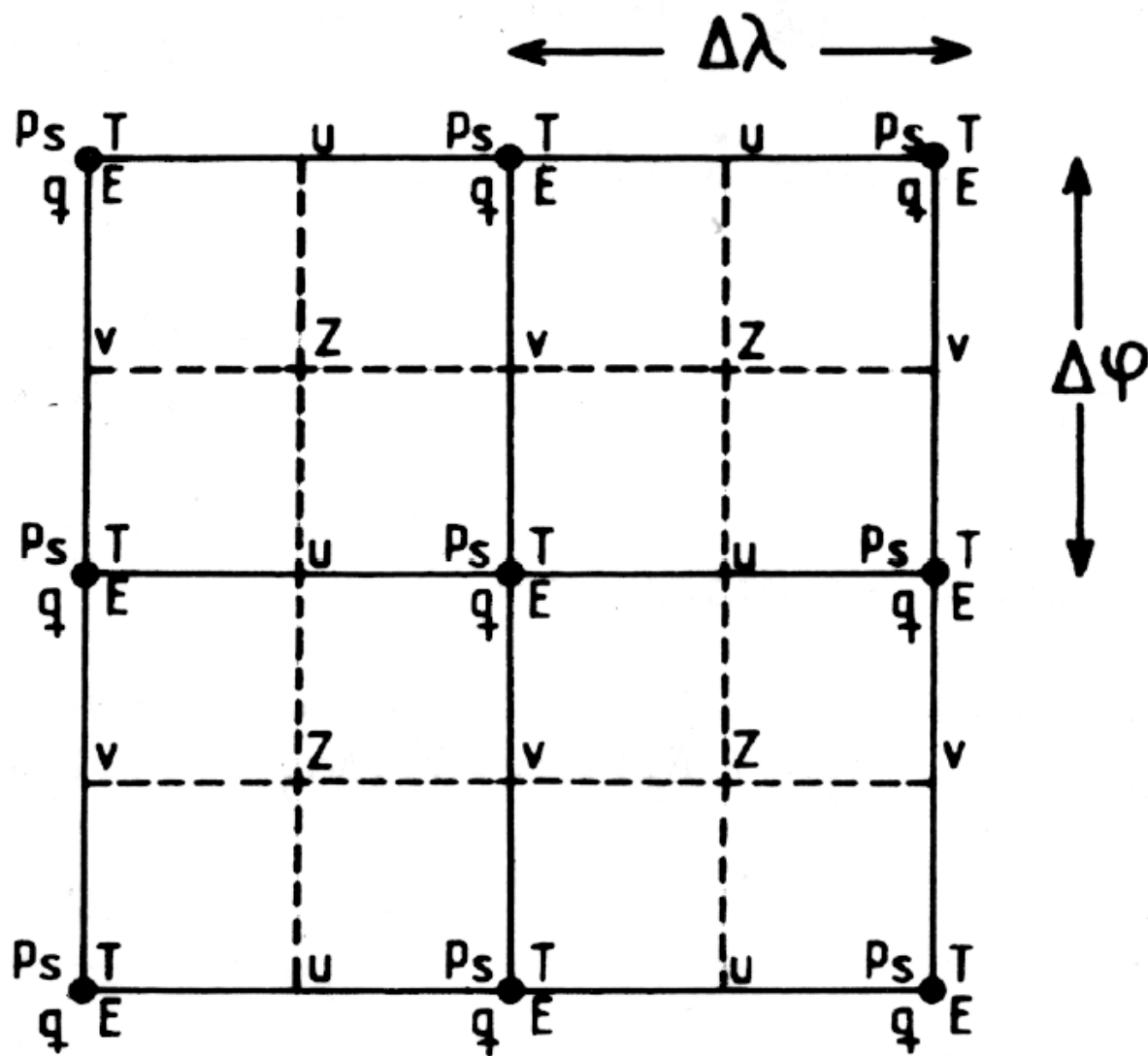


Gridding of observations

Statistical interpolation of observations only
2 m temperature and precipitation and more

CRU data sets global ~ 50 km 1901 -
E-OBS data sets Europe land ~25 km 1955 -
GPCC global precipitation ~ 50 km 110 years

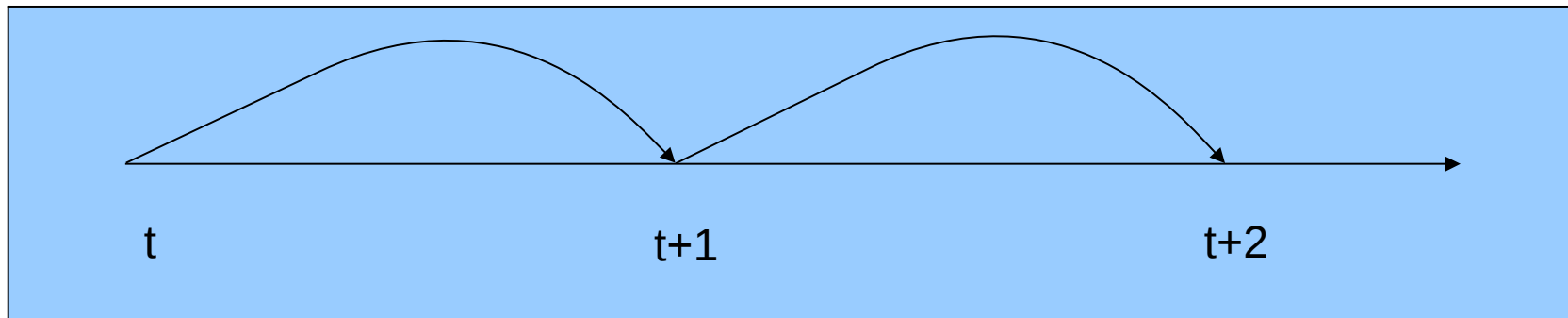
Several regional-national data sets
Alpine gridded data set precipitation 5 km
Nordic gridded data set 1 km 1981-
UK, KNMI, SMHI, MF, DWD



←→ Δx

←→ $\Delta \lambda$ (våglängd)

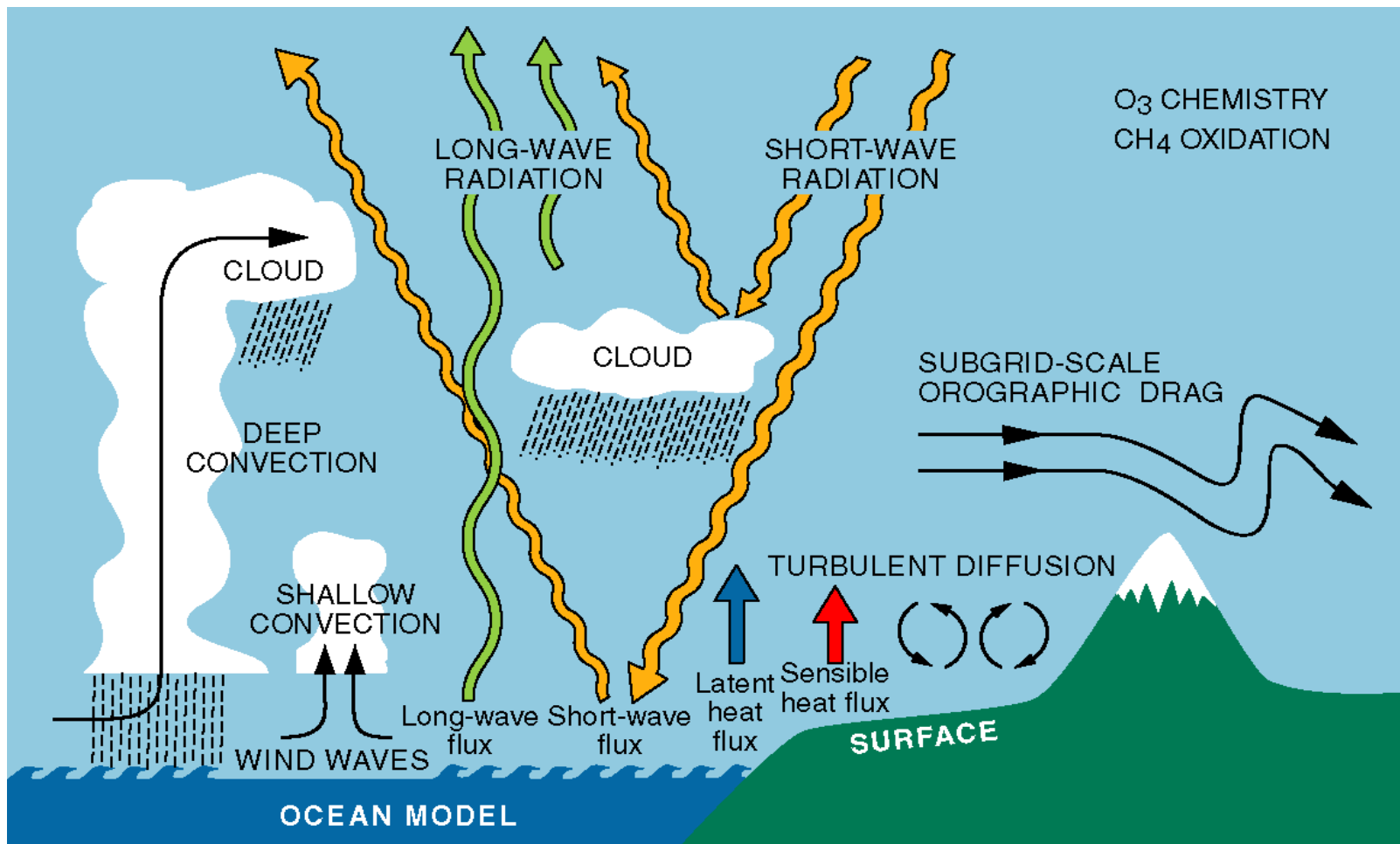
Time integration of the differential equations



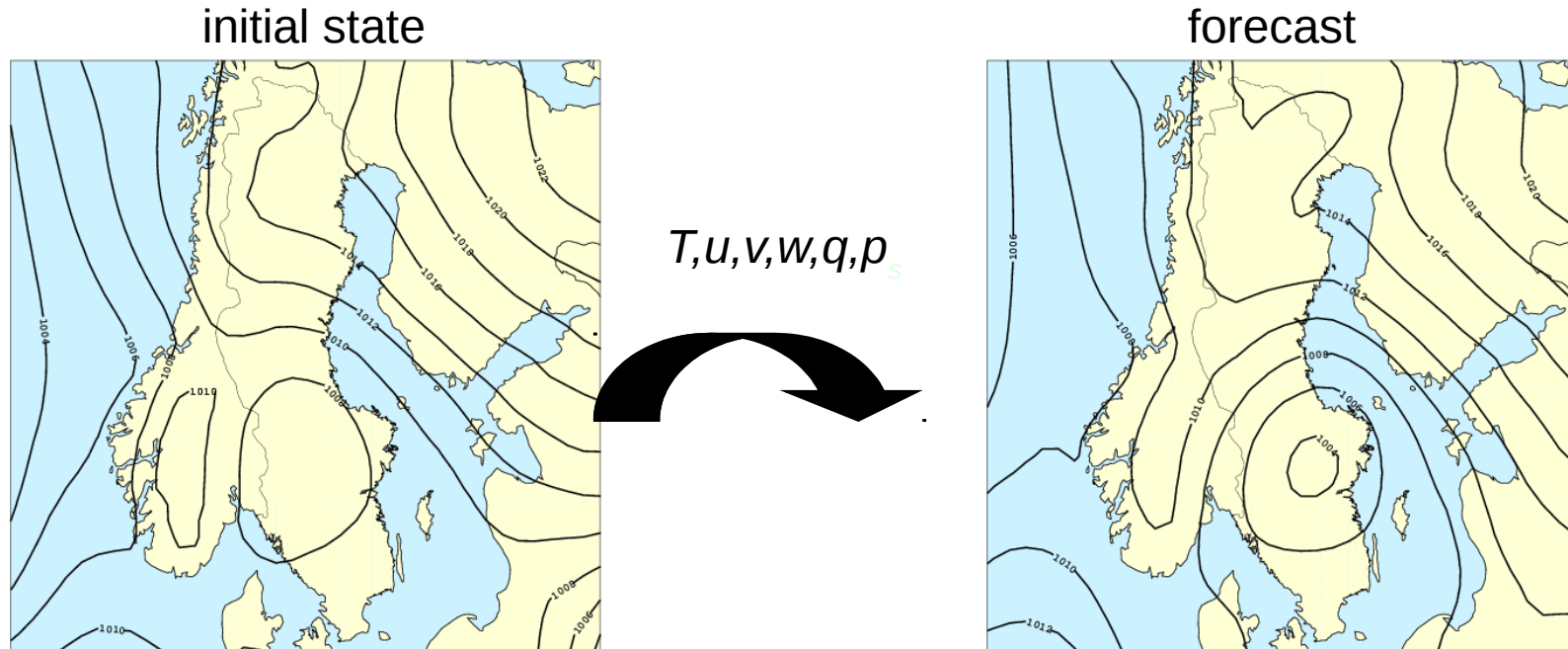
- Equations for tendencies of pressure, temperature, wind, moisture and water and more
- Update new atmospheric state at all grid points
- Compute new tendencies
 - $U(t+1) = U(t) + \text{forces and physical process}$
 -

Parameterisation of processes between gridpoints at scales not resolved

- No natural separation in reality
- Model resolution determines what parameterisation needed
- Compute statistics of sub-grid processes and add that aggregated effect - enables diagnostic computations of e.g. radiative fluxes



Numerical Weather Prediction

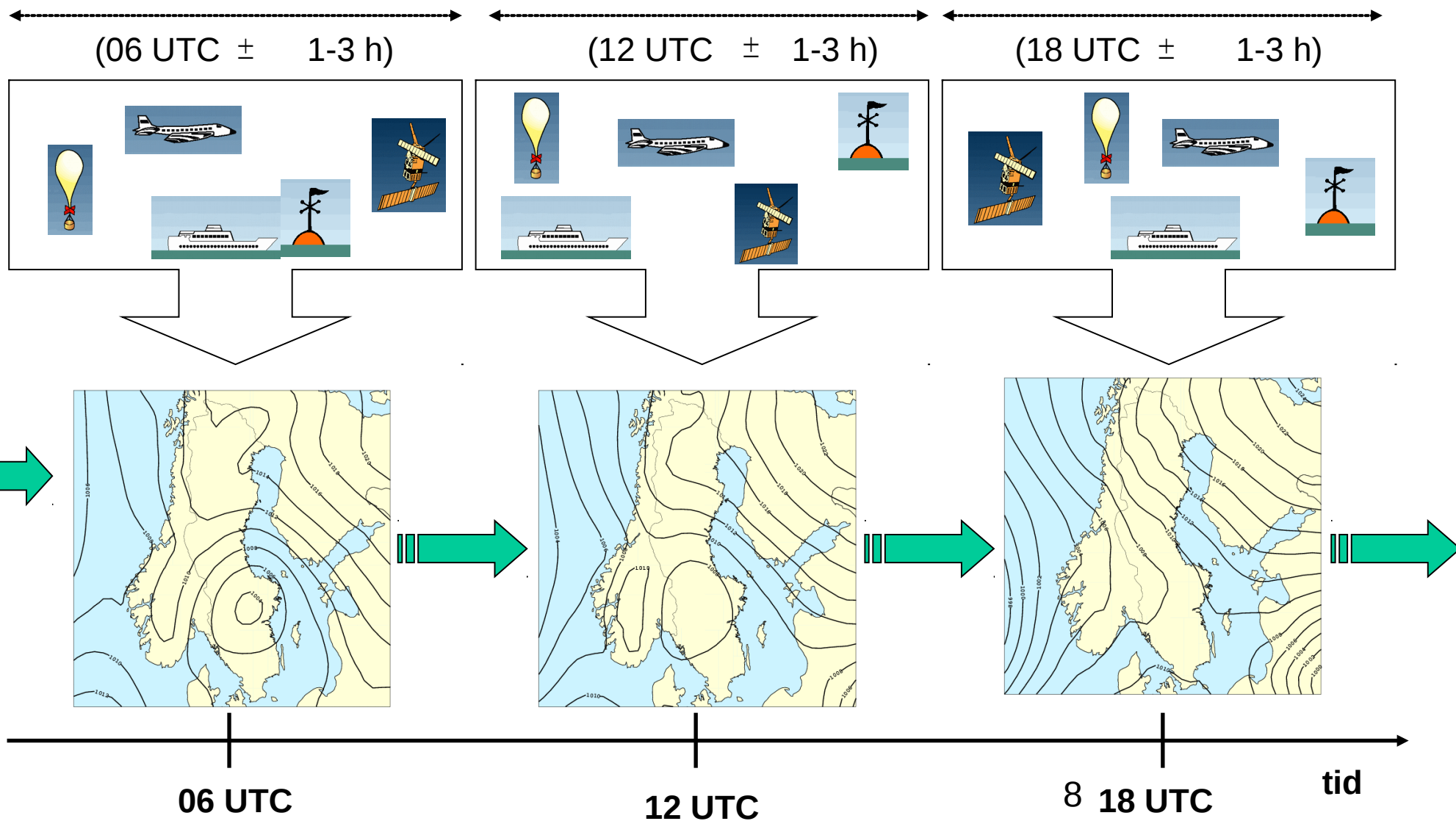


KI 00

KI 00 + 6 tim = 06

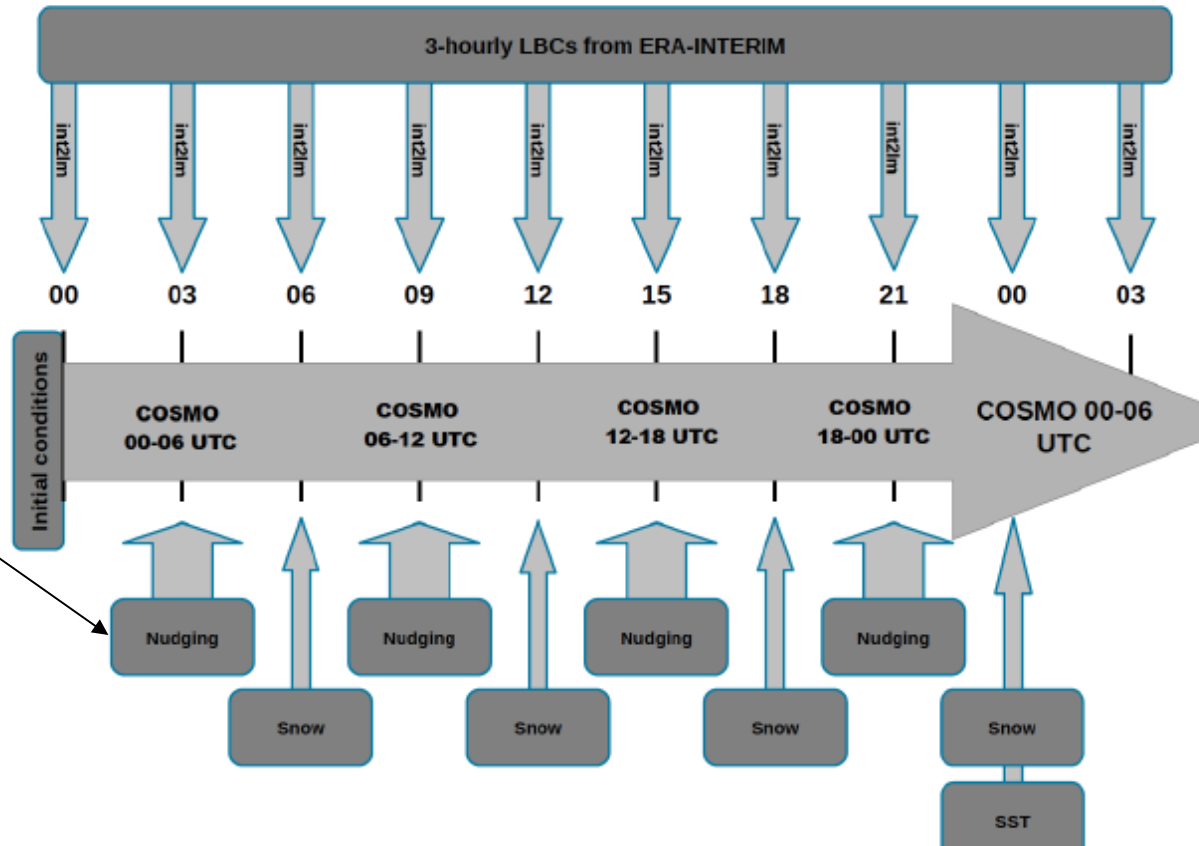
Integrate forecast for next analysis 3 or 6 hours ahead

Data assimilation



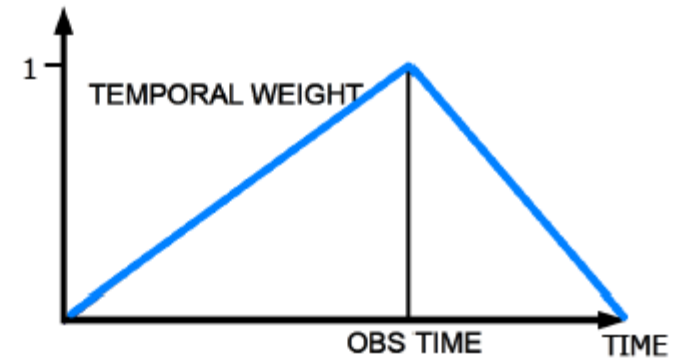
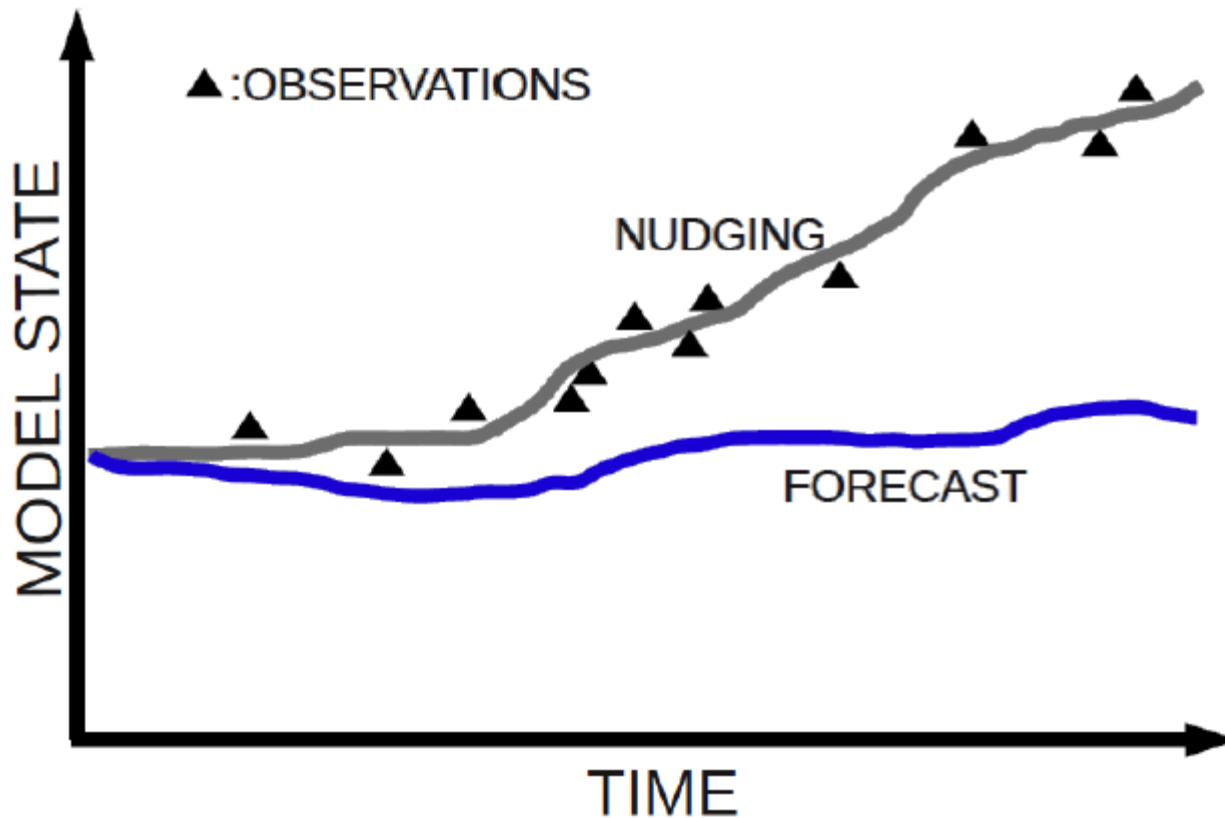
Data assimilation of Observations

```
graph TD
    InitRun --> Build
    Build --> CollectLogs
    CollectLogs --> MakeCycleInput
    MakeCycleInput --> Date_analysis
    Date_analysis --> Cycle
    Cycle --> StartData
    StartData --> Analysis
    Analysis --> Addsurf
    Addsurf --> AnSFC
    AnSFC --> AnUA
    AnUA --> PostAnalysis
    PostAnalysis --> CollectLogs
    CollectLogs --> Date_forecast
    Date_forecast --> Postprocessing
    Postprocessing --> Disk_cleaning
    Disk_cleaning --> Archive_ecgate
    Archive_ecgate --> CollectLogs
    CollectLogs --> LogProgress
    LogProgress --> EndOfMonth
    EndOfMonth --> Wrapup
```



COSMO University Bonn / DWD

Ensemble nudging



Background for reanalyses

From FGGE first GARP global experiment
Additional radiosondes and drifting buoys –
1978/79 level IIIb "reanalysis"

Bengtsson and Shukla (1988)
Observing system performance, predictability,
general circulation, low frequency variability

ERA-15 global reanalysis to cover this

Reanalysis principle

Observations as complete as possible or improving



NWP model and analysis system remain fixed

Reanalysis quality remains the same or improving

1961

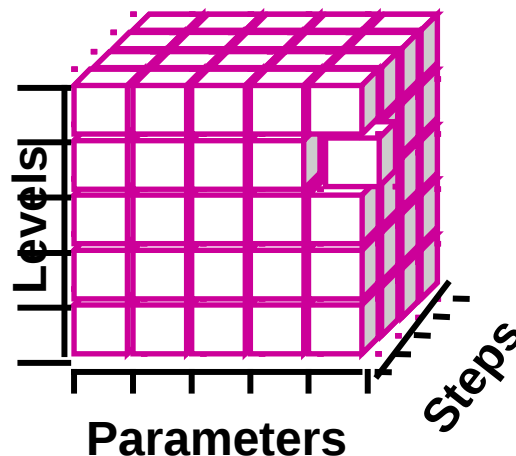


2014

ARCHIVING IN MARS

Data Services

- + *The common UERRA archive is MARS at ECMWF*
 - Common set of parameters chosen for all models*
 - GRIB2 (some new definitions)*
- + *Data services from MARS and ESGF interface*
- + *Web Map Servers*
- + *Visualisation through Metview and WMS*



Global reanalyses – ERA-15 – Observing systems developments
ERA-40, Interim, ERA-20C. and ERA-5 Copernicus

Helsinki WMO conference – need for regional reanalyses

North American efforts
NCEP Climate reanalysis
NCEP 20CR
NASA MERRA-2
NCEP RRA
ASR 2000-10

Japanese
JRA-55

EU Commission and SPACE programme
DAMOCLES Arctic ocean and "lightly" coupled atmosphere
EURO4M
UERRA

COSMO RRA 6 km (1995-2015)
MÉRA 2.5 km (1981-2015)

CMA
India
Australia

Spain, Italy,
Netherlands
and more

Organization	Time Period	Resolution	Analysis Method
ECMWF FGGE	1979	1.875° * 1.875°	Optimal interpolation
NASA Data Assimilation Office (DAO)	1980 to 1994	2x2.5° lat/lon ($\Delta x \sim 280\text{km}$) L20 (σ , top at 10hPa)	Optimal Interpolation (OI) with incremental analysis update
ECMWF (ERA-15)	1979 to 1993	T106 spectral ($\Delta x \sim 125\text{km}$) L31 (σ -p, top at 10hPa)	Optimal Interpolation (OI) with nonlinear normal mode initialization
NOAA NCEP and NCAR (R1)	1948 to present	T62 spectral ($\Delta x \sim 200\text{km}$) L28 (σ , top at 3hPa)	Spectral Statistical Interpolation (SSI)
NOAA NCEP and DOE (R2)	1979 to present	T62 spectral ($\Delta x \sim 200\text{km}$) L28 (σ , top at 3hPa)	Spectral Statistical Interpolation (SSI)
ECMWF (ERA-40)	1957 to 2002	T159 spectral ($\Delta x \sim 100\text{km}$) L60 (σ -p, top at 0.1hPa)	3D-Var , direct radiance assimilation
JMA and CRIEPI (JRA-25)	1979 to 2004	T106 spectral ($\Delta x \sim 125\text{km}$) L40 (σ -p, top at 0.4hPa)	3D-Var , direct radiance assimilation
ECMWF (ERA-Interim)	1989 to present	T255 spectral ($\Delta x \sim 80\text{km}$) L60 (σ -p, top at 0.1hPa)	4D-Var , variational bias correction of radiance data (VarBC)
NCEP (CFSRR)	1979 to 2009	T382 spectral ($\Delta x \sim 38\text{km}$) L64 (σ -p, top at 0.2hPa)	Grid-point Statistical Interpolation (GSI) <i>with weakly coupled ocean</i>
NASA GMAO (MERRA)	1979 to present	0.5x0.67° lat/lon ($\Delta x \sim 74\text{km}$) L72 (σ -p, top at 0.01hPa)	Grid-point Statistical Interpolation (GSI)
JMA (JRA-55)	1958 to 2012 (just completed)	T319 spectral ($\Delta x \sim 63\text{km}$) L60 (σ -p, top at 0.1hPa)	4D-Var , variational bias correction of radiance data (VarBC)
20th Century Reanalysis (NOAA ESRL)	1871 to 2010	2° * 2°	Ensemble Kalman Filter surface data

Regional Reanalyses

North American Regional Reanalysis 32km

Arctic System Reanalysis 10km

South Asia Regional Reanalysis 18km

EURO4M reanalysis 12/22km

+ downscaler 5km

UERRA reanalysis 11/12km

+ downscaler 5km

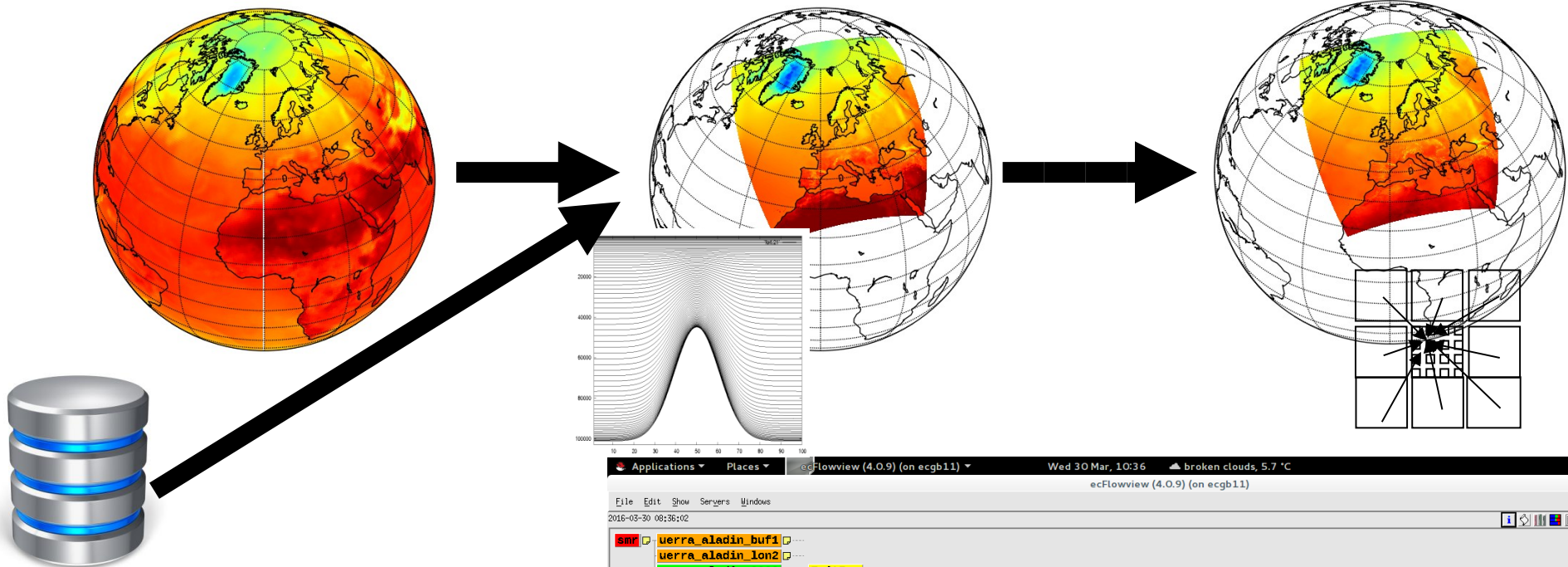
C3S European reanalysis 5.5 km

C3S Arctic reanalysis 2 x 2.5 km

2-dim downscaling & reanalysis

3-dim regional reanalysis

ERA-INTERIM reanalysis boundaries



```
Applications Places ecfFlowview (4.0.9) (on ecgb11) Wed 30 Mar, 10:36 broken clouds, 5.7 °C sv  
ecfFlowview (4.0.9) (on ecgb11)  
File Edit Show Servers Windows  
2016-03-30 08:36:02  
smf uerra_aladin_buf1  
uerra_aladin_lon2  
uerra_aladin_9099  
InitRun  
Build  
CollectLogs ( ( Build == aborted or Build == complete ) and InitRun == complete )  
MakeCycleInput  
Date_analysis YMD=... 19891118 ...  
( Build == complete )  
Hour HH=0 6 ...  
{ ( ( ../Date_analysis:YMD <= 19890901 ) and ( Hour:HH < 00 ) ) or ( ( ../Date_analysis:YMD >= 19891231 )  
Cycle { ( ( ../MakeCycleInput == complete ) or ( ../MakeCycleInput:YMD > ../Date_analysis:YMD ) )  
StartData { StartData == complete )  
Analysis { Addsurf  
AnSFC  
AnUA  
PostAnalysis  
CollectLogs ( Cycle == aborted or Cycle == complete )  
Date_forecast
```

OBSERVATIONS
GLOBAL ANALYSIS
REGIONAL REANALYSIS

- + Regional reanalyses driven by global forcing and upper-air and surface observations using frozen systems
- + Multi-model and ensembles of reanalyses
- + Surface and upper-air parameters

MESCAN downscaling ensemble analyses

MESAN – CANARI

- Swedish and French/ALADIN surface analysis system combined and run at 5.5 km

SMHI HARMONIE ALADIN @ 11 km

- ALADIN physics ->
- ALARO physics ->
 - Interpolate first guess 6 hour forecast
 - Interpolate analysis → run ALADIN 5.5 km forecast
 - SURFEX soil scheme
 - ISBA soil scheme
 - » Perturb observations
 - » Reduced network



HARMONIE (HIRLAM ALADIN Regional/Mesoscale Operational NWP In Europe)

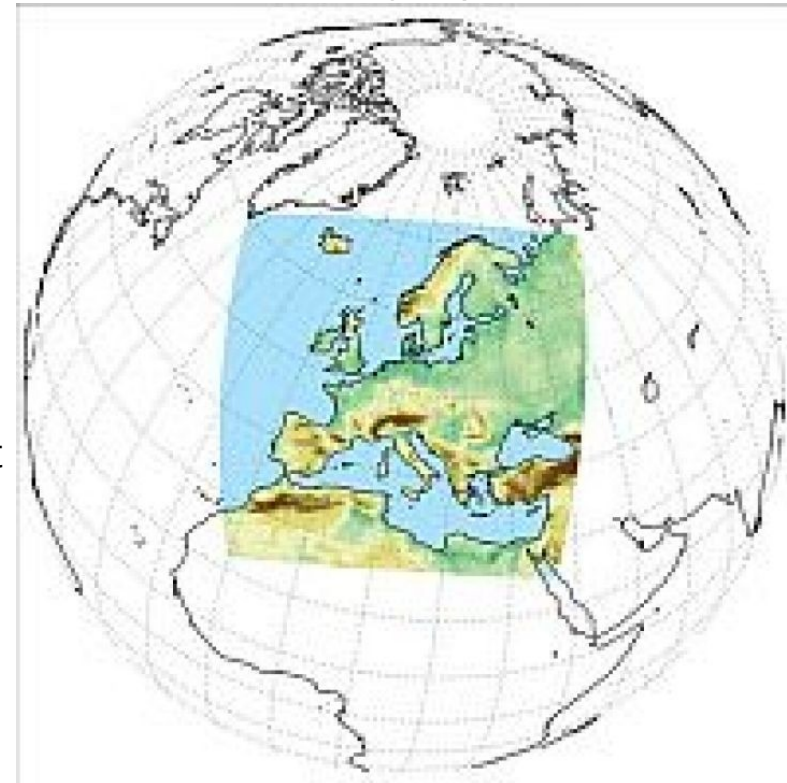
HARMONIE-ALADIN re-analysis: 1961-2015

- HARMONIE
 - Cy38h1.1
 - 11 km horizontal resolution, 65 vertical levels
 - 30 hour forecasts at 00 and 12
 - 1 hour resolution up to 6 hours and 3 hour after that

- Data assimilation
 - 3DVar for upper air – Conventional observations (SYNOP, Ship, Buoys, Radiosondes, Pilot and Aircraft)
 - Large scale constraint – Jk
 - OI for the surface – T2m, RH2m and snow water equivalent

- Observations and Boundaries
 - 1961-2001 we used ERA40 observations with addition of Swedish and French observations in the early years. After that operational data
 - 1961-1979 we used ERA40 boundaries. After that ERAinterim

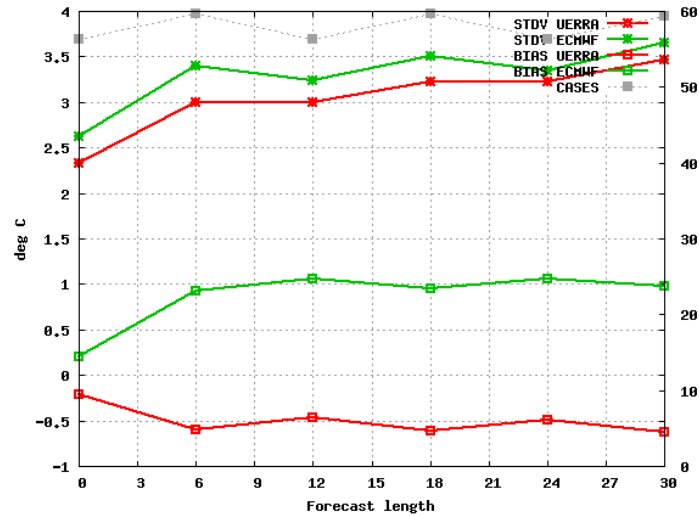
EURO-CORDEX domain 4
576x576 grid points



Verification of T2m, winter

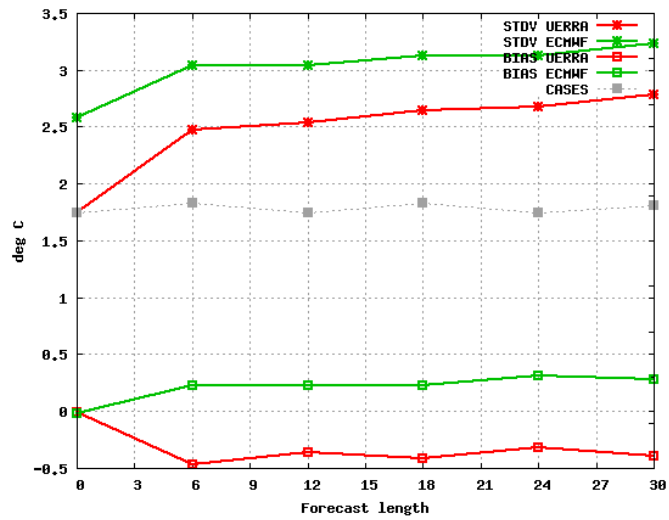
1962

Selection: ALL using 756 stations
T2m Period: 196212 -196302
Hours: {00,12}



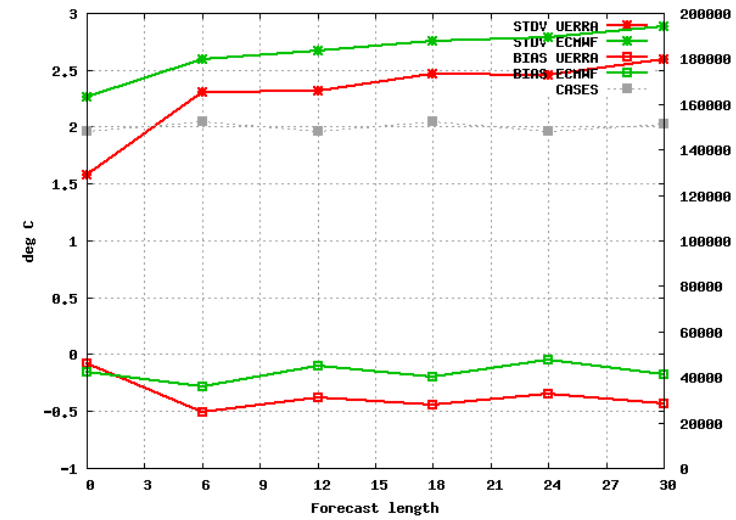
1972

Selection: ALL using 1614 stations
T2m Period: 197212 -197302
Hours: {00,12}



1982

Selection: ALL using 1722 stations
T2m Period: 198212 -198302
Hours: {00,12}

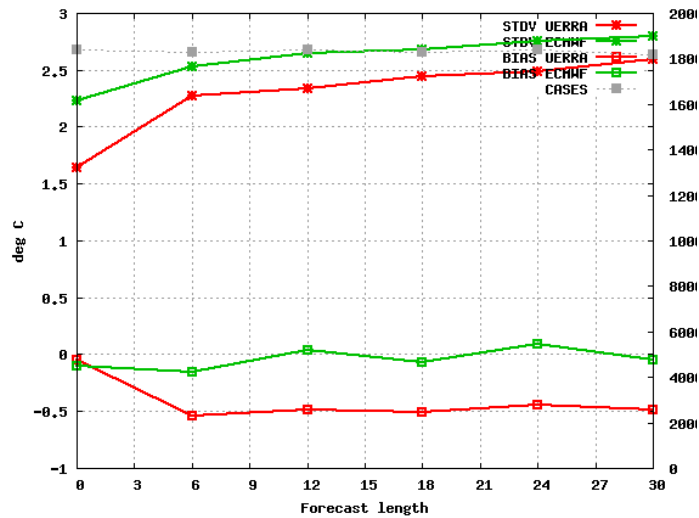


Red: UERRA

Green: ERA

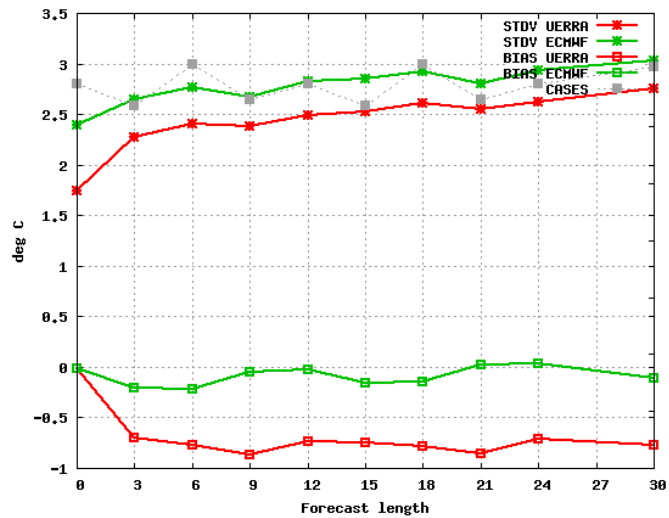
1992

Selection: ALL using 1817 stations
T2m Period: 199212 -199302
Hours: {00,12}



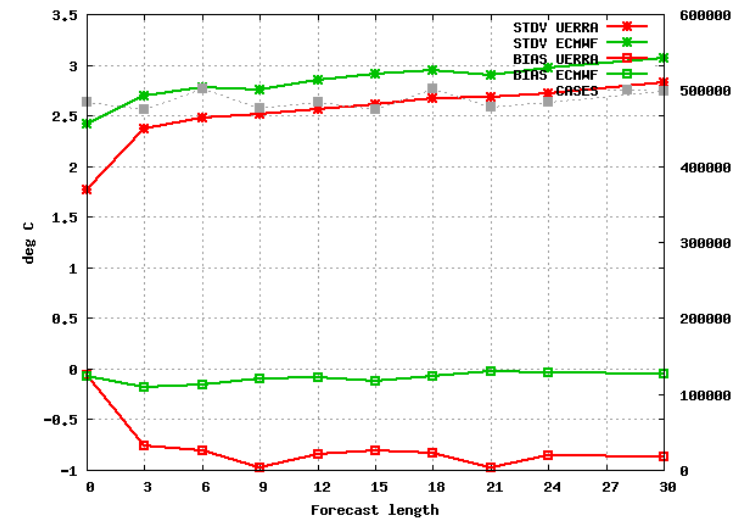
2002

Selection: ALL using 2185 stations
T2m Period: 200212 -200302
Hours: {00,12}



2012

Selection: ALL using 2950 stations
T2m Period: 201212 -201302
Hours: {00,12}

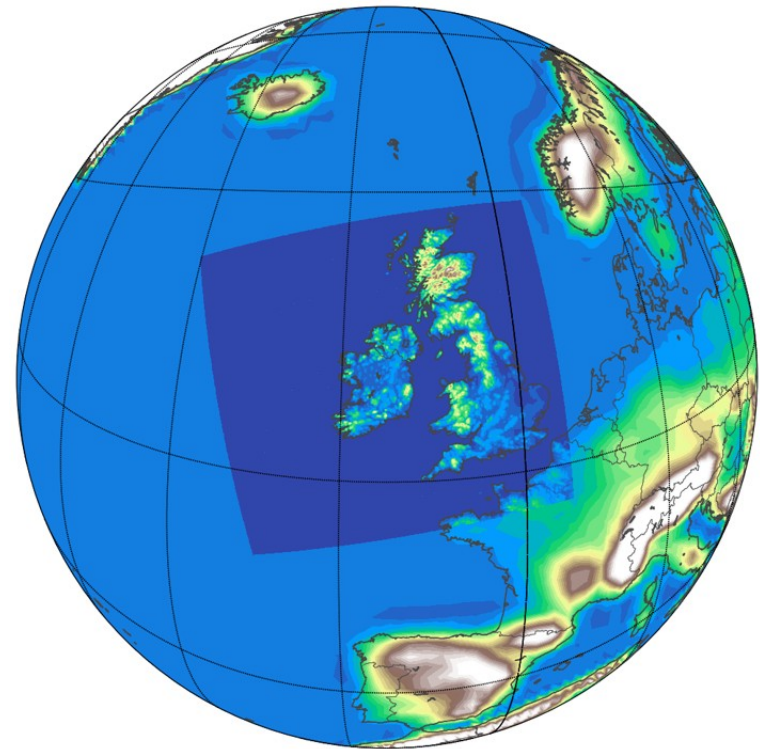


MÉRA: ALADIN-HIRLAM NWP System

- AHNS used by 26 NHMS Europe & North Africa
- Used operationally by Met Éireann since 2011
- HARMONIE-AROME configuration (cycle 38h1.2)
 - 2.5km horizontal grid-spacing
 - 65 levels with highest level at 10hPa

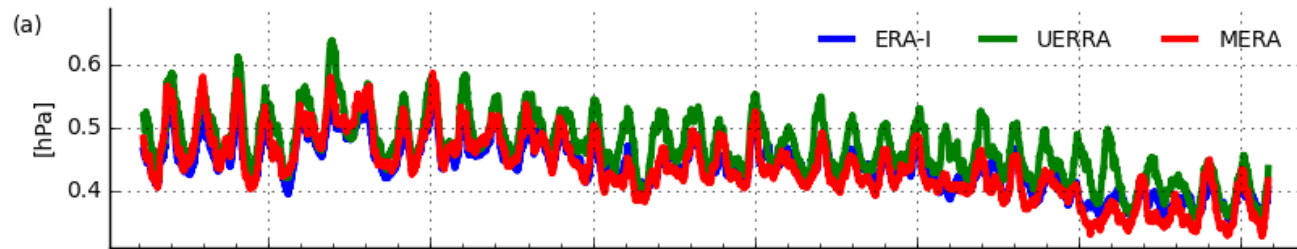
 - ALADIN non-hydrostatic dynamics
 - MESO-NH mesoscale physics
 - SURFEX surface model

 - 3D-Var upper-air data assimilation
 - OI surface data assimilation

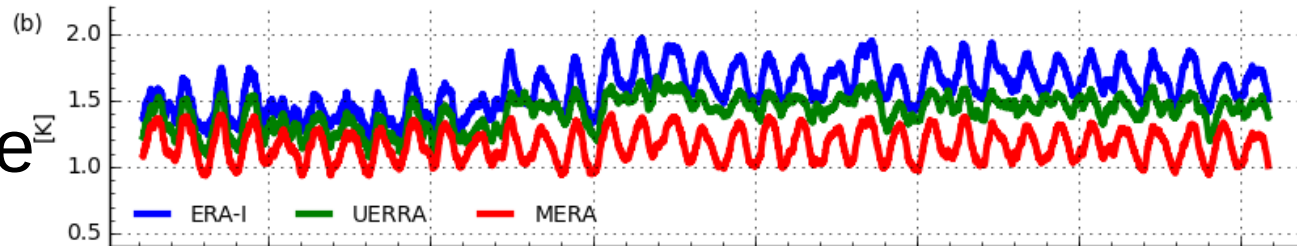


Forecast performance

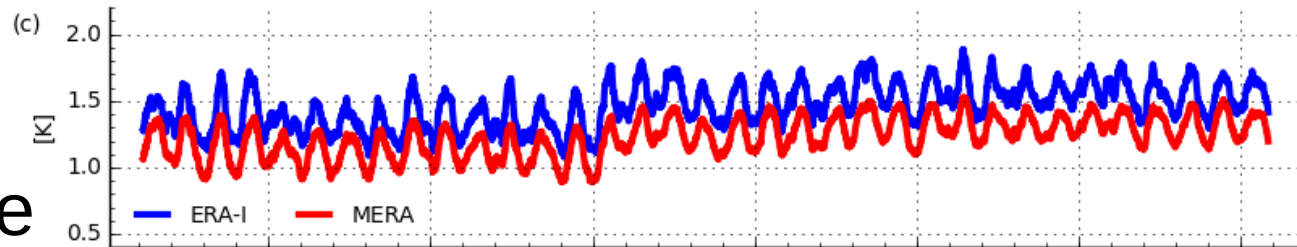
PMSL



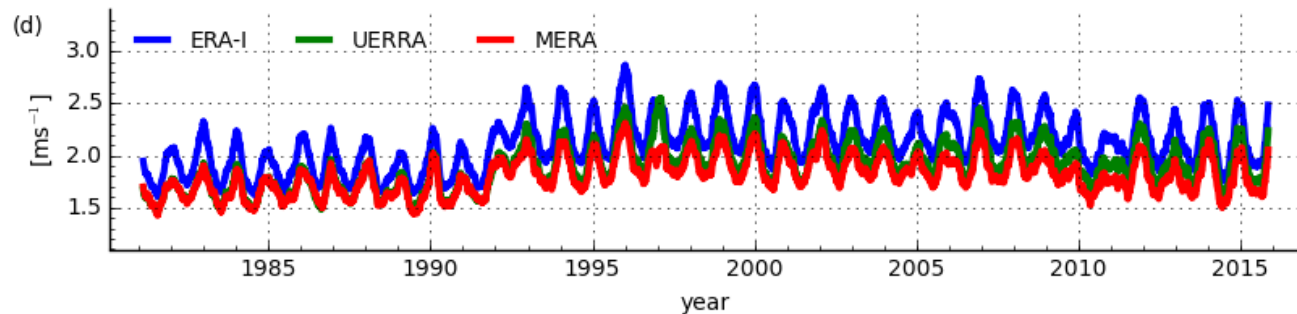
Temperature [K]

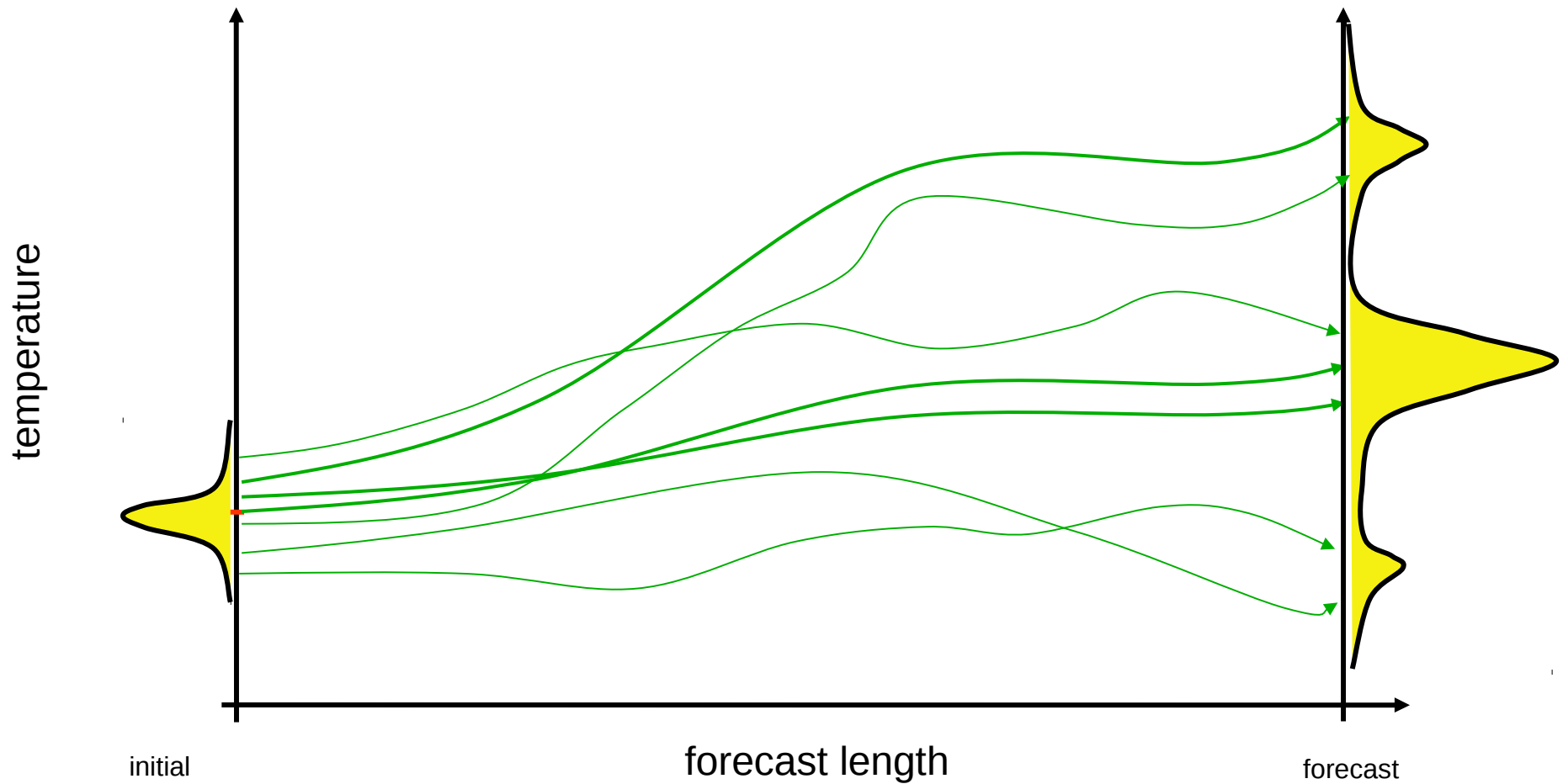


Corrected Temperature [K]



Wind [ms⁻¹]

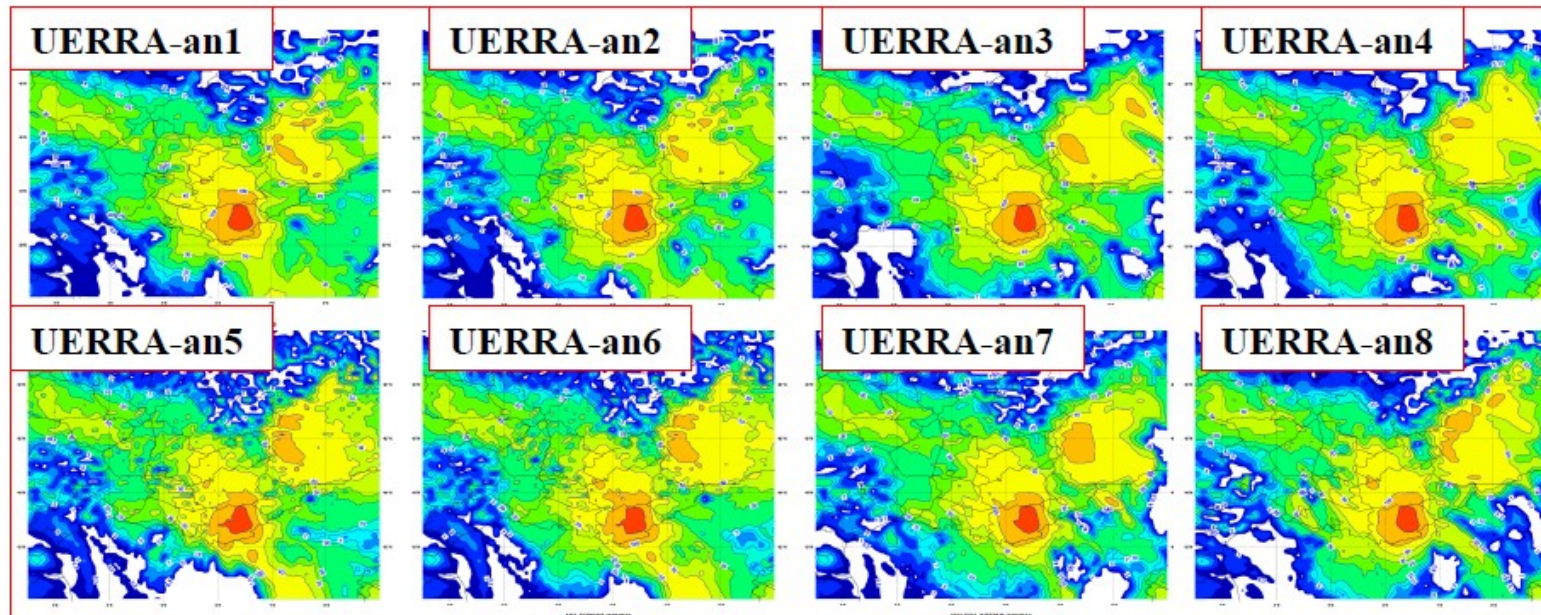




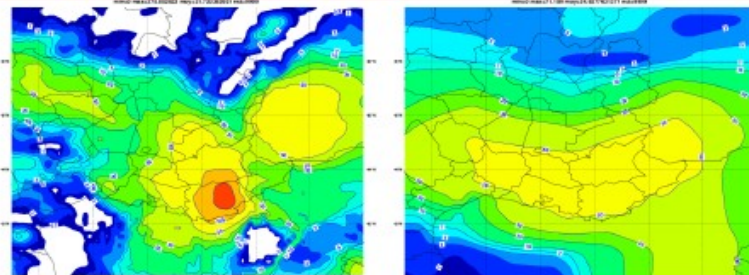
the weather development as a
Probability Density Function (PDF)

Ensemble members due to different model backgrounds

Extreme precipitation events of 15 June 2010
8 members : RR24h UERRA Analysis



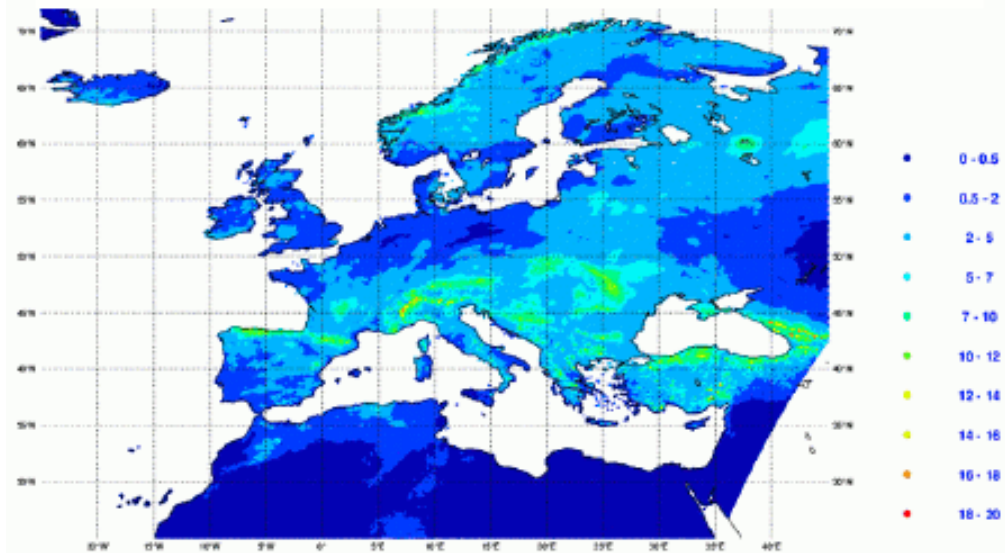
EURO4M



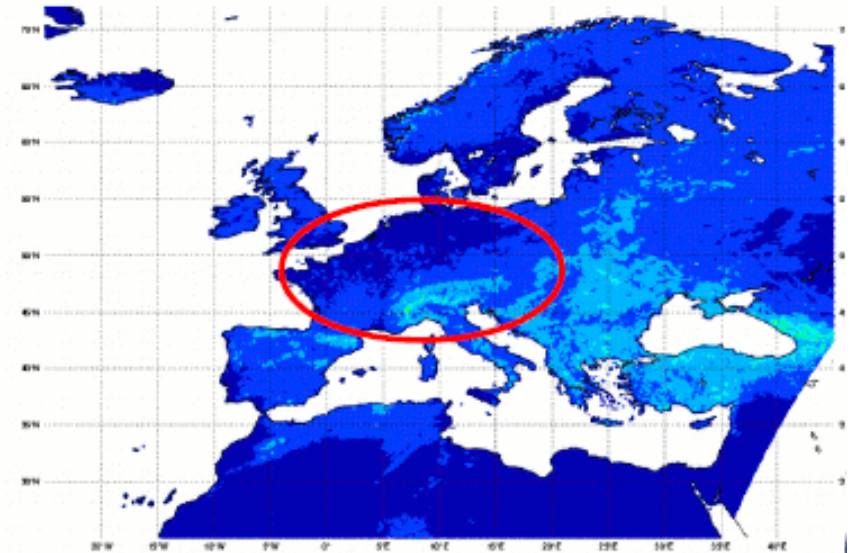
ERA-INTERIM

Statistics and uncertainty from ensemble

Ensemble Mean of Analyses



Ensemble Mean SD of Analyses



Lessons learned from the pre-operational Copernicus projects

Need to make potential users aware of the possibilities of modern reanalysis data

More work to assess and reduce long term Biases

Need to develop data assimilation and model based reanalysis systems different from operational systems (especially regional) since they are of different resolutions and domains