The Irish Regional Ensemble (IRE): Development of a convection-permitting Ensemble Prediction System at Met Éireann

Alan Hally, Rónán Darcy, Colm Clancy, Eoin Whelan

Shedding light on the greyzone, 13th – 16th Nov. 2017, ECMWF, Reading

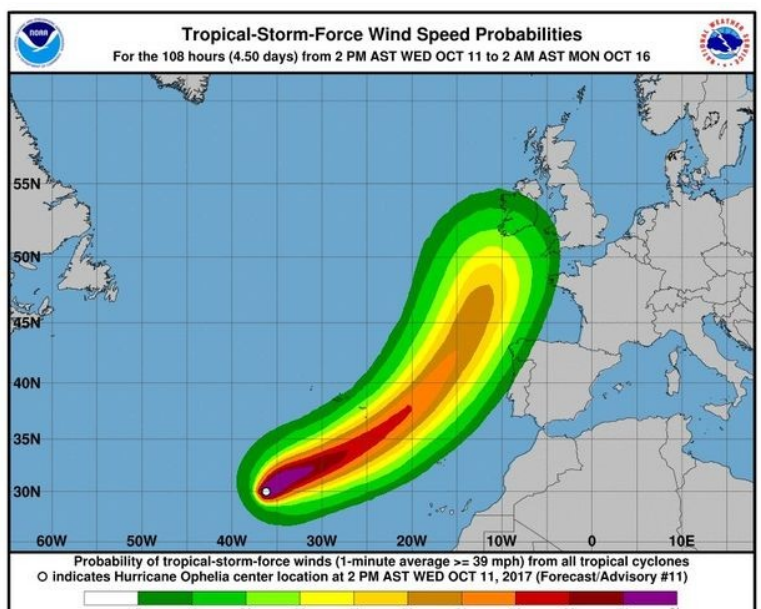
Motivation for developing IRE?

Improved short-range forecasting of high-impact weather events over Ireland

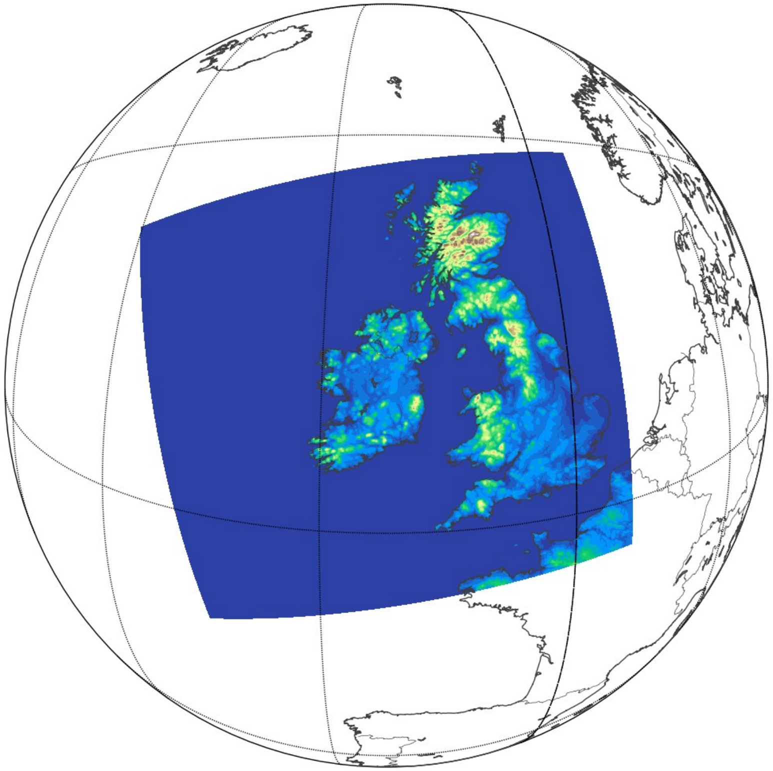
Doris

Donegal

Ophelia



Description of HARMONIE–AROME Model



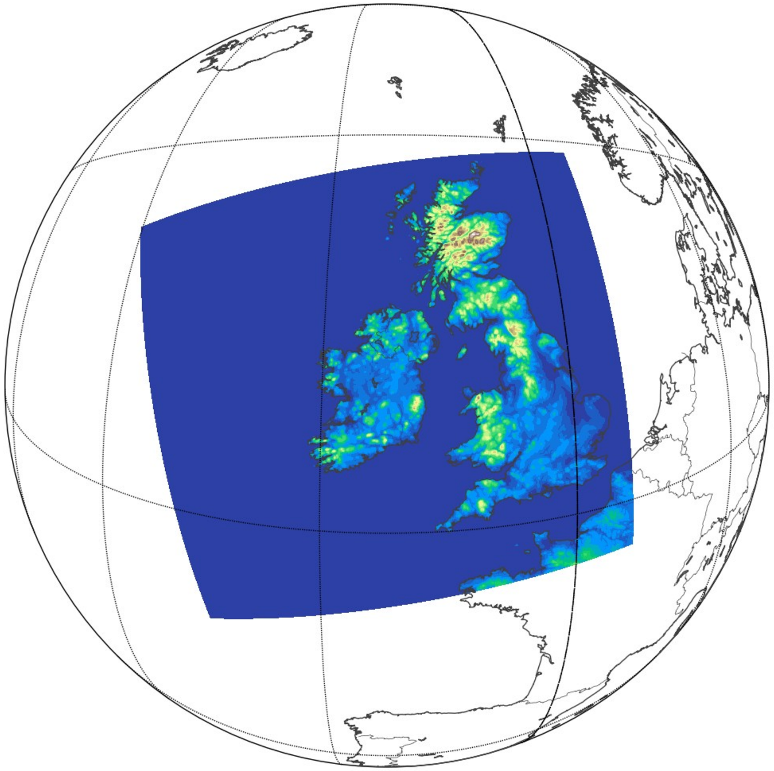
Met Éireann run cycle 37h1.1 of HARMONIE-AROME
2.5km resolution every 6 hours, 60s timestep

Domain: 540x500x65
Model top @ 10hPa

Observations=> Conventional only
Observational cut-off window=> 45 mins
Data assimilation: Surface analysis only with blending (on a 6hr cycle)

Forecasts: 54 hours @ 00, 06, 12 & 18UTC
Boundaries: IFS

Description of HARMONIE–AROME Model

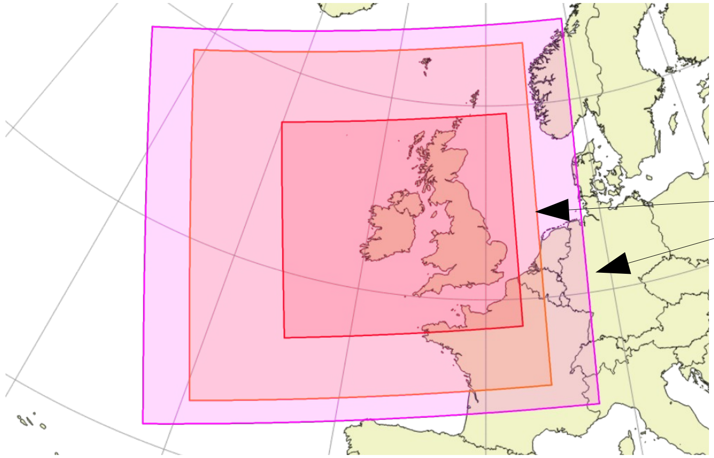


Met Éireann run cycle 37h1.1 of HARMONIE-AROME
2.5km resolution every 6 hours, 60s timestep

Domain: 540x500x65
Model top @ 10hPa

Observations=> Conventional only
Observational cut-off window=> 45 mins
Data assimilation: Surface analysis only with blending (on a 6hr cycle)

Forecasts: 54 hours @ 00, 06, 12 & 18UTC
Boundaries: IFS



Upgrade to cycle 40 of HARMONIE-AROME

2 possibilities for domain upgrades

Data assimilation: Conventional observations using 3D-Var

Other updates in physics & dynamics

Proposed initial architecture of IRE

Scaled Lagged Average Forecasting (SLAF) (Ebisuzaki & Kalnay, 1991)

The basic idea of **SLAF** is that perturbations are taking **HRES** forecasts valid at the same time but with **different forecast lengths** and **initial times**

Proposed initial architecture of IRE

Scaled Lagged Average Forecasting (SLAF) (Ebisuzaki & Kalnay, 1991)

The basic idea of **<u>SLAF</u>** is that perturbations are taking **<u>HRES</u>** forecasts valid at the same time but with **<u>different forecast lengths</u>** and **<u>initial times</u>**

$$IC_m = A_c + (+/-K_m)*(IFS_0 - IFS_{N-6})$$
$$BC_m = IFS_0 + (+/-K_m)*(IFS_N - IFS_{N-6})$$

IC_m = initial condition for member m

BC_m = lateral boundary condition for member m

A_c = the control analysis

K_m = a scaling factor known as SLAFK

IFS_0 = the latest available IFS forecast

N = the forecast length for an earlier forecast valid at the same time

IFS_N = forecast with length N, valid at the same time as the analysis

IFS_{N-6} = forecast with length N-6 i.e. 6 hours shorter than IFS_N, valid at the same time as the analysis

Proposed initial architecture of IRE

Scaled Lagged Average Forecasting (SLAF) (Ebisuzaki & Kalnay, 1991)

The basic idea of **SLAF** is that perturbations are taking **HRES** forecasts valid at the same time but with **different forecast lengths** and **initial times**

Pros

- Cheap in terms of communication of boundary conditions (BCs) from single global model
- Have some control over spread of initial conditions (ICs) and lateral boundary conditions (LBCs)
- Easy to implement in HARMONIE-AROME
- Experience of using SLAF set-up at other HIRLAM centres

Proposed initial architecture of IRE

Scaled Lagged Average Forecasting (SLAF) (Ebisuzaki & Kalnay, 1991)

The basic idea of **SLAF** is that perturbations are taking **HRES** forecasts valid at the same time but with **different forecast lengths** and **initial times**

Pros

- Cheap in terms of communication of boundary conditions (BCs) from single global model
- Have some control over spread of initial conditions (ICs) and lateral boundary conditions (LBCs)
- Easy to implement in HARMONIE-AROME
- Experience of using SLAF set-up at other HIRLAM centres

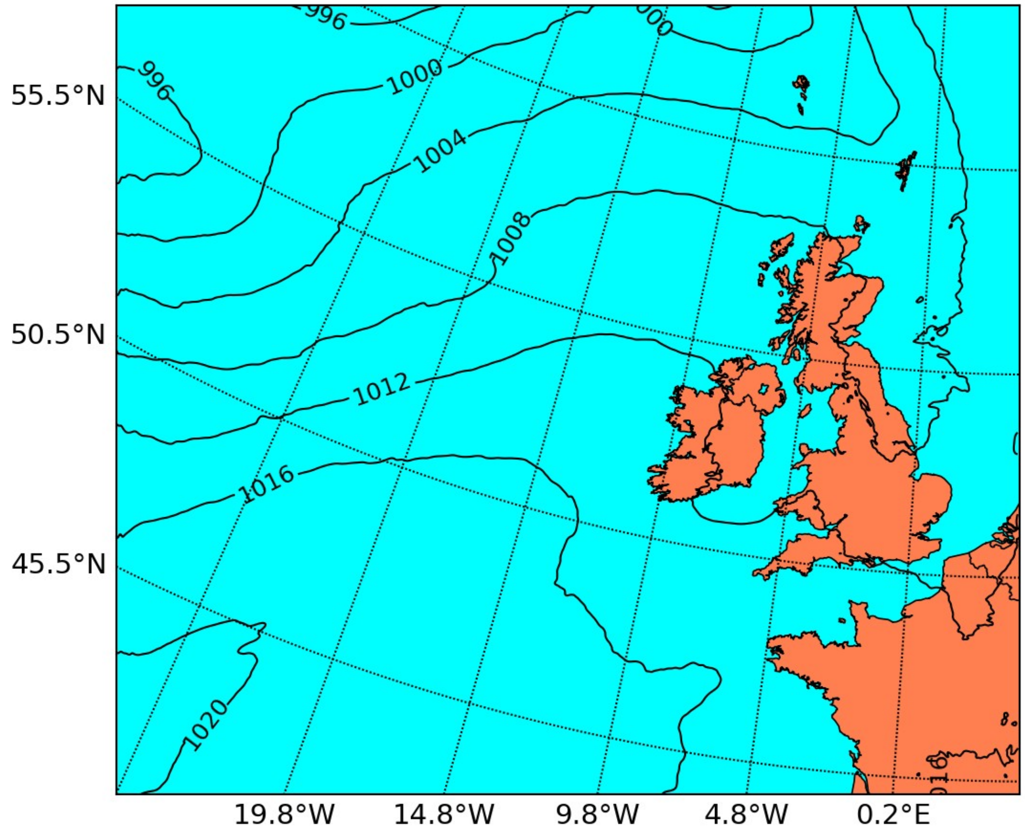
Cons

- Number of potential members is limited
- Linearity is assumed through the scaling and addition/subtraction of perturbations
- No representation of observational uncertainty

Initial test set-up

Test cases chosen

High-impact events → Storm Doris (23rd Feb. 2017), Donegal rain (22nd - 23rd Aug. 2017), Hurricane/Post-Tropical Storm Ophelia (16th Oct. 2017)



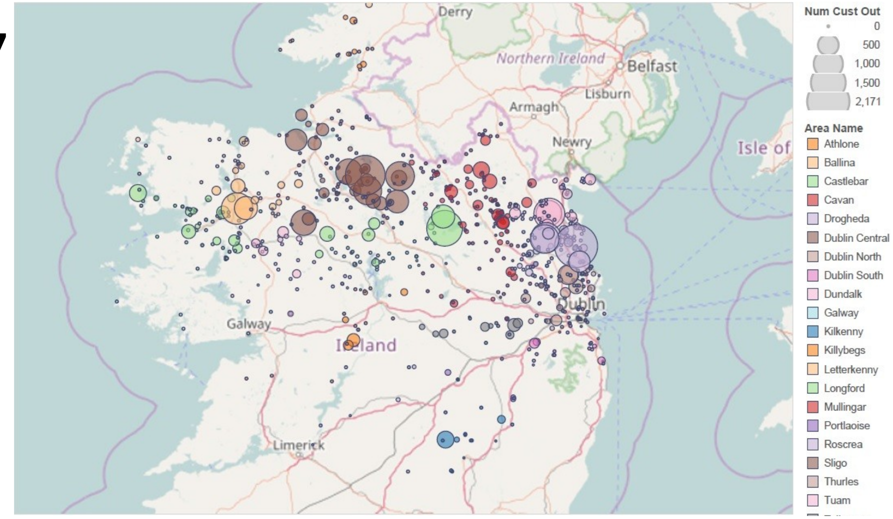
Technical set-up details:

← +36hr forecasts, every 3hrs

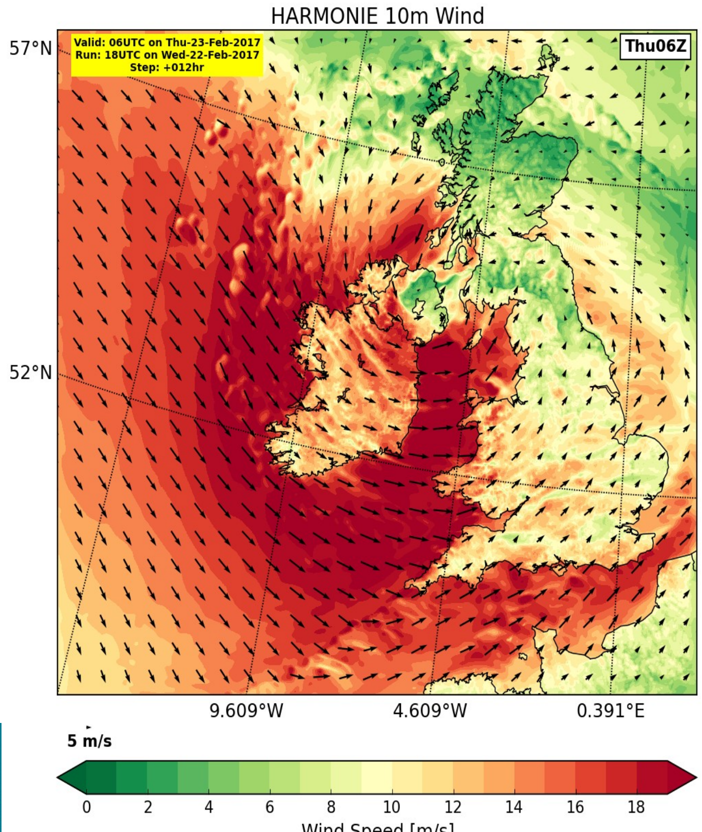
10+1 members

Initial test results

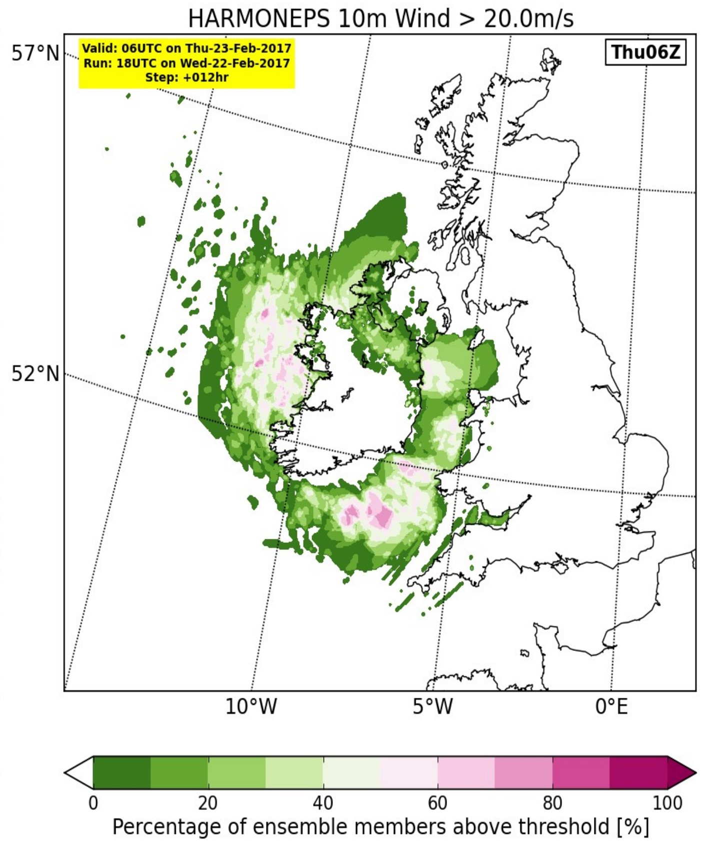
Storm Doris: 23rd of February 2017



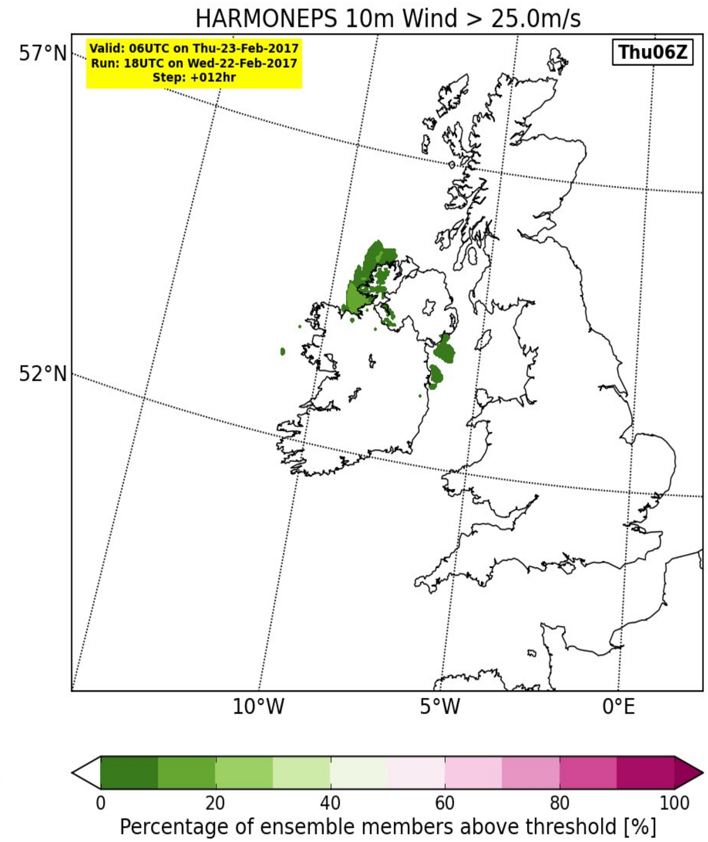
Operational HARMONIE-AROME forecast from 18UTC on 22nd Feb: Valid @ 06UTC on 23rd Feb



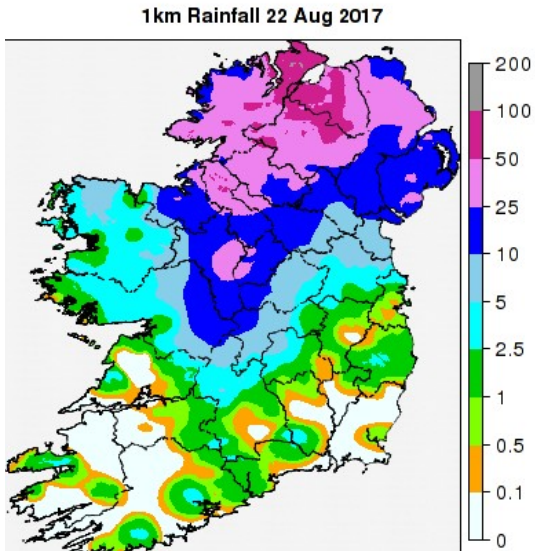
IRE forecast from 18UTC on 22nd Feb: Valid @ 06UTC on 23rd Feb



IRE forecast from 18UTC on 22nd Feb: Valid @ 06UTC on 23rd Feb

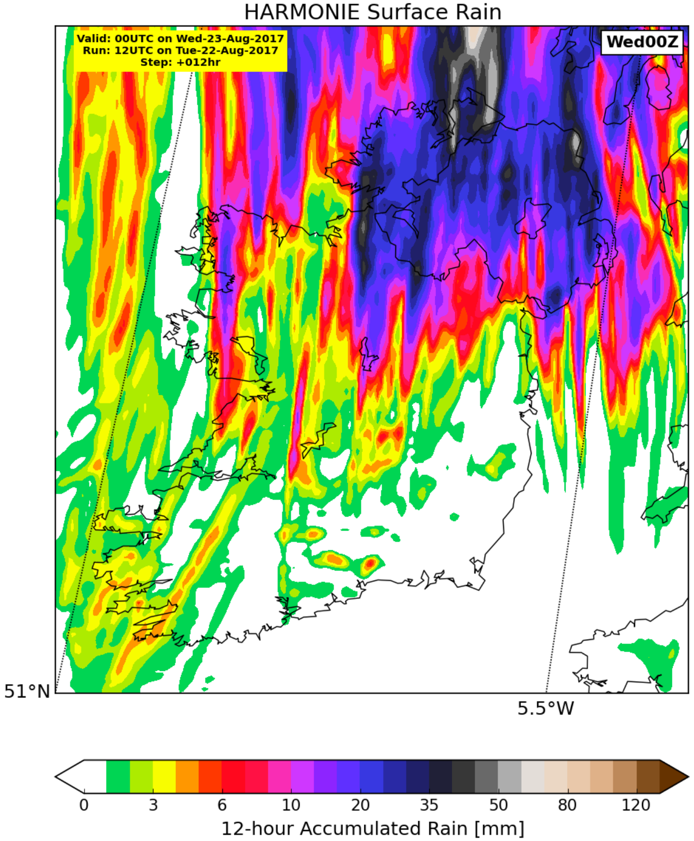


Heavy rainfall Donegal: 22nd of August 2017



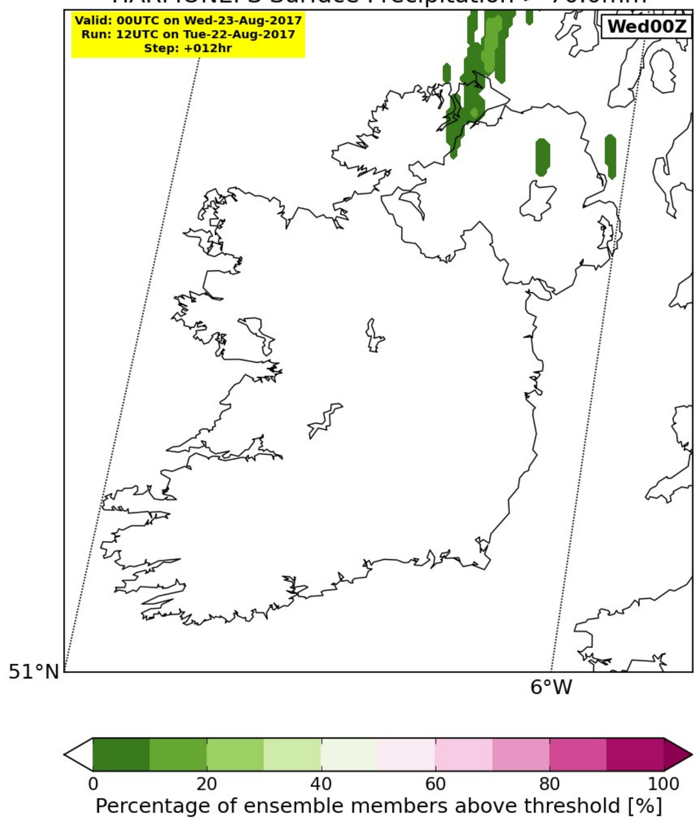
Operational HARMONIE-AROME forecast from 12UTC on 22nd Aug: Valid @ 00UTC on 23rd Aug

HARMONIE Surface Rain



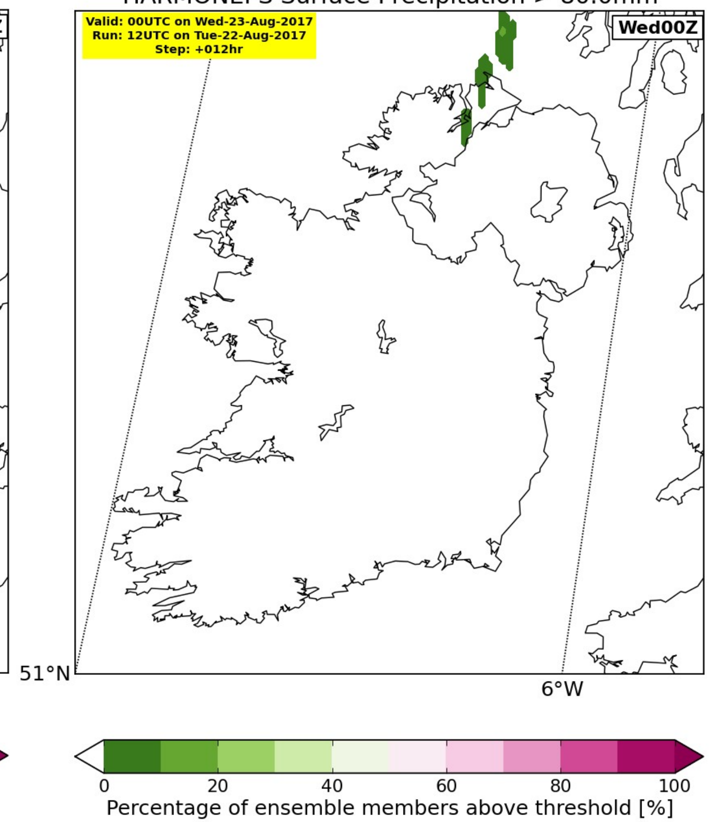
IRE forecast from 12UTC on 22nd Aug: Valid @ 00UTC on 23rd Aug

HARMONEPS Surface Precipitation > 70.0mm



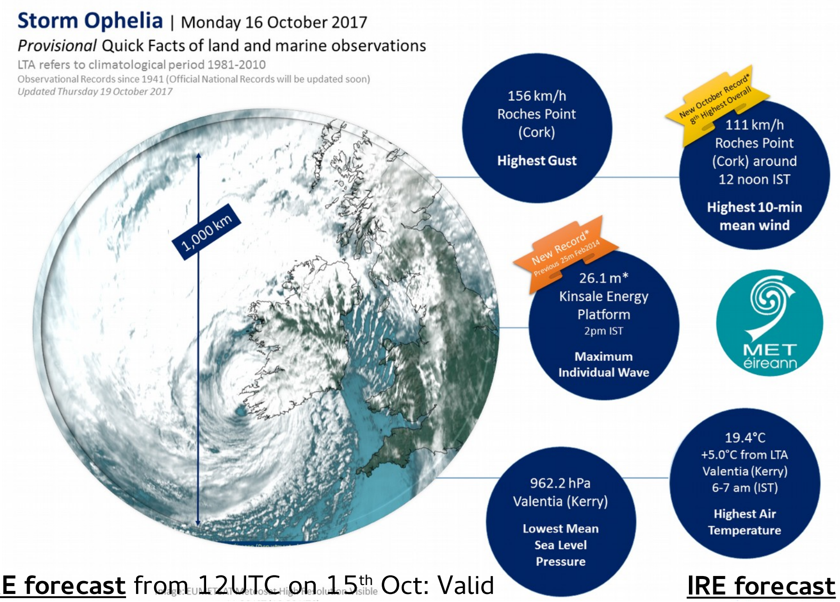
IRE forecast from 12UTC on 22nd Aug: Valid @ 00UTC on 23rd Aug

HARMONEPS Surface Precipitation > 80.0mm

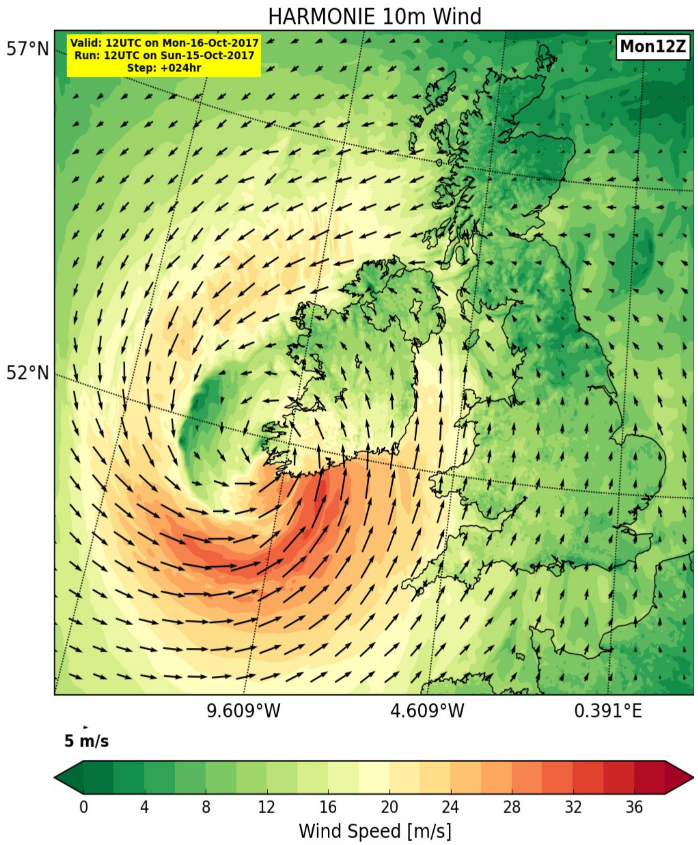


Initial test results

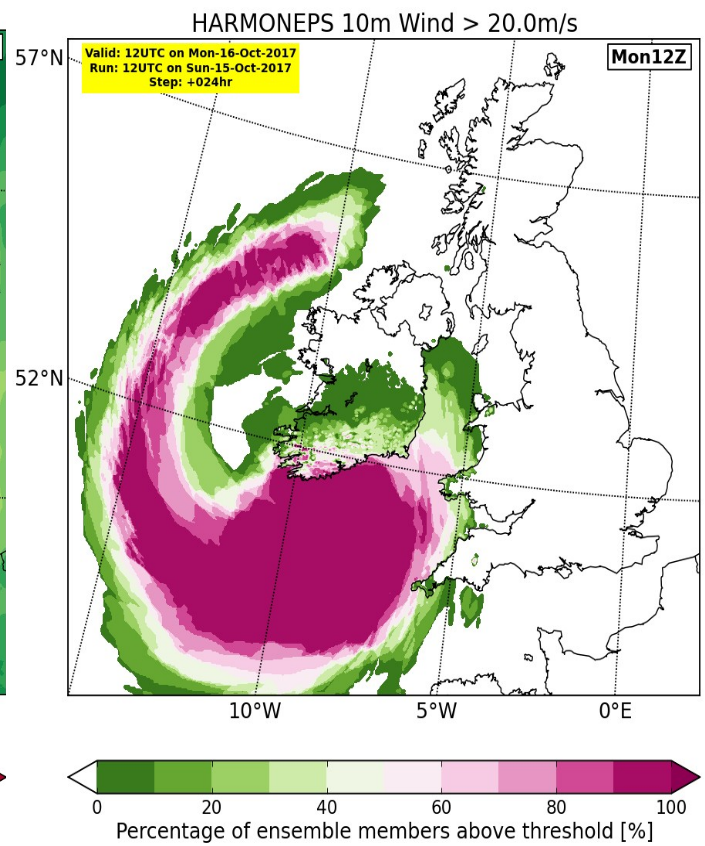
Ophelia: 16th of October 2017



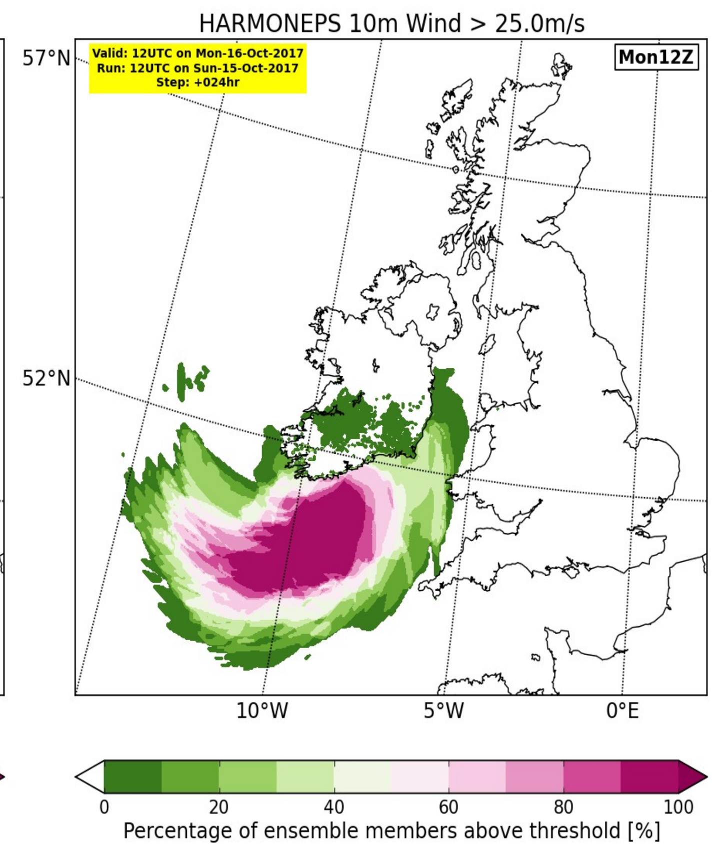
Operational HARMONIE-AROME forecast from 12UTC on 15th Oct: Valid @ 12UTC on 16th Oct



IRE forecast from 12UTC on 15th Oct: Valid @ 12UTC on 16th Oct



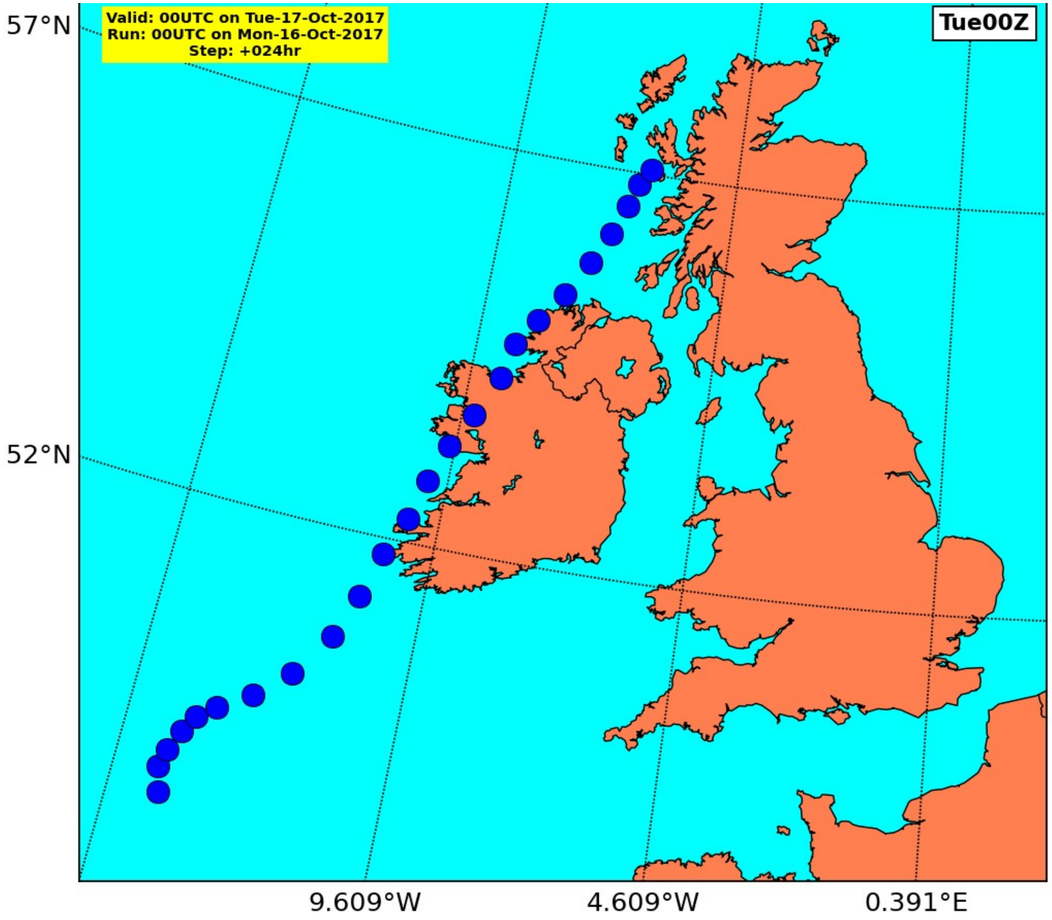
IRE forecast from 12UTC on 15th Oct: Valid @ 12UTC on 16th Oct



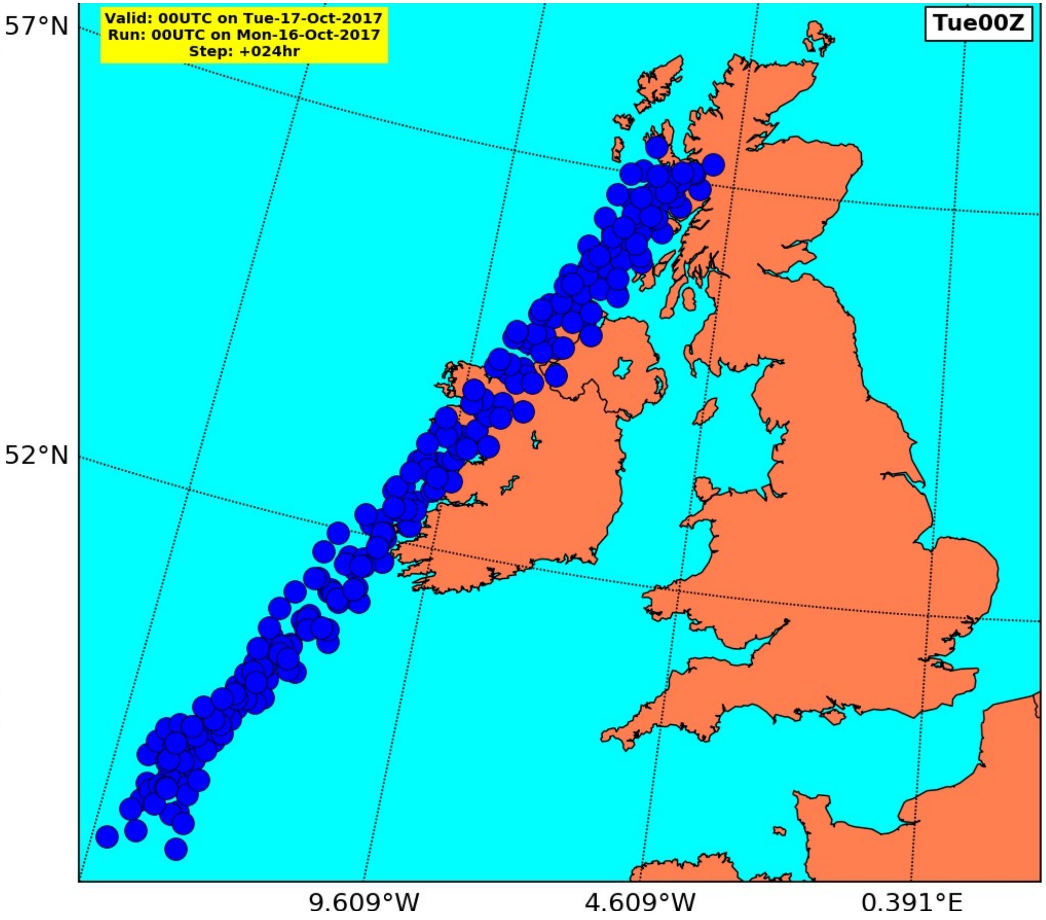
Initial test results

Projected track of Ophelia: 16th of October 2017

Operational HARMONIE-AROME forecast from 00UTC on 16th Oct: Valid @ 00UTC on 17th Oct



IRE forecast from 00UTC on 16th Oct: Valid @ 00UTC on 17th Oct



Information gleamed from initial tests

→ Ensembles added value in all three cases

→ The values of the perturbation factor (SLAFK) still need to be tuned (default values used in all test cases)

→ The SLAF method needs to be compared to downscaling ECMWF-ENS members as ICs and BCs

→ Method of delivery of probabilistic information

Wishlist

Future developments to IRE/wishlist of desirable aspects

→ The inclusion of a representation of physical parameterisation uncertainty

Multiple physics (tedious to maintain), SPPT (possible drying effect in lower boundary layer), SPP (yet to be implemented in HARMONIE), perturbations of microphysical/turbulence time tendencies (testing and implementation work to be done)

→ The use of ECMWF-ENS members as ICs and LBCs for IRE

Would require the development of a clustering technique to choose random ENS members (as @ Météo-France, Nuissier et al 2012)

Wishlist

Future developments to IRE/wishlist of desirable aspects

→ The inclusion of a representation of physical parameterisation uncertainty

Multiple physics (tedious to maintain), SPPT (possible drying effect in lower boundary layer), SPP (yet to be implemented in HARMONIE), perturbations of microphysical/turbulence time tendencies (testing and implementation work to be done)

→ The use of ECMWF-ENS members as ICs and LBCs for IRE

Would require the development of a clustering technique to choose random ENS members (as @ Météo-France, Nuissier et al 2012)

→ The use of the Ensemble of Data Assimilations (EDA) method with perturbed observations to represent initial condition uncertainty

Computationally expensive

→ Extension to longer time ranges, 48-54h, so as to be in-line with deterministic forecast

Computationally more expensive

Wishlist

Future developments to IRE/wishlist of desirable aspects

The inclusion of a representation of physical parameterisation uncertainty

Multiple physics (tedious to maintain), SPPT (possible drying effect in lower boundary layer), SPP (yet to be implemented in HARMONIE), perturbations of microphysical/turbulence time tendencies (testing and implementation work to be done)

The use of ECMWF-ENS members as ICs and LBCs for IRE

Would require the development of a clustering technique to choose random ENS members (as @ Météo-France, Nuissier et al 2012)

The use of the Ensemble of Data Assimilations (EDA) method with perturbed observations to represent initial condition uncertainty

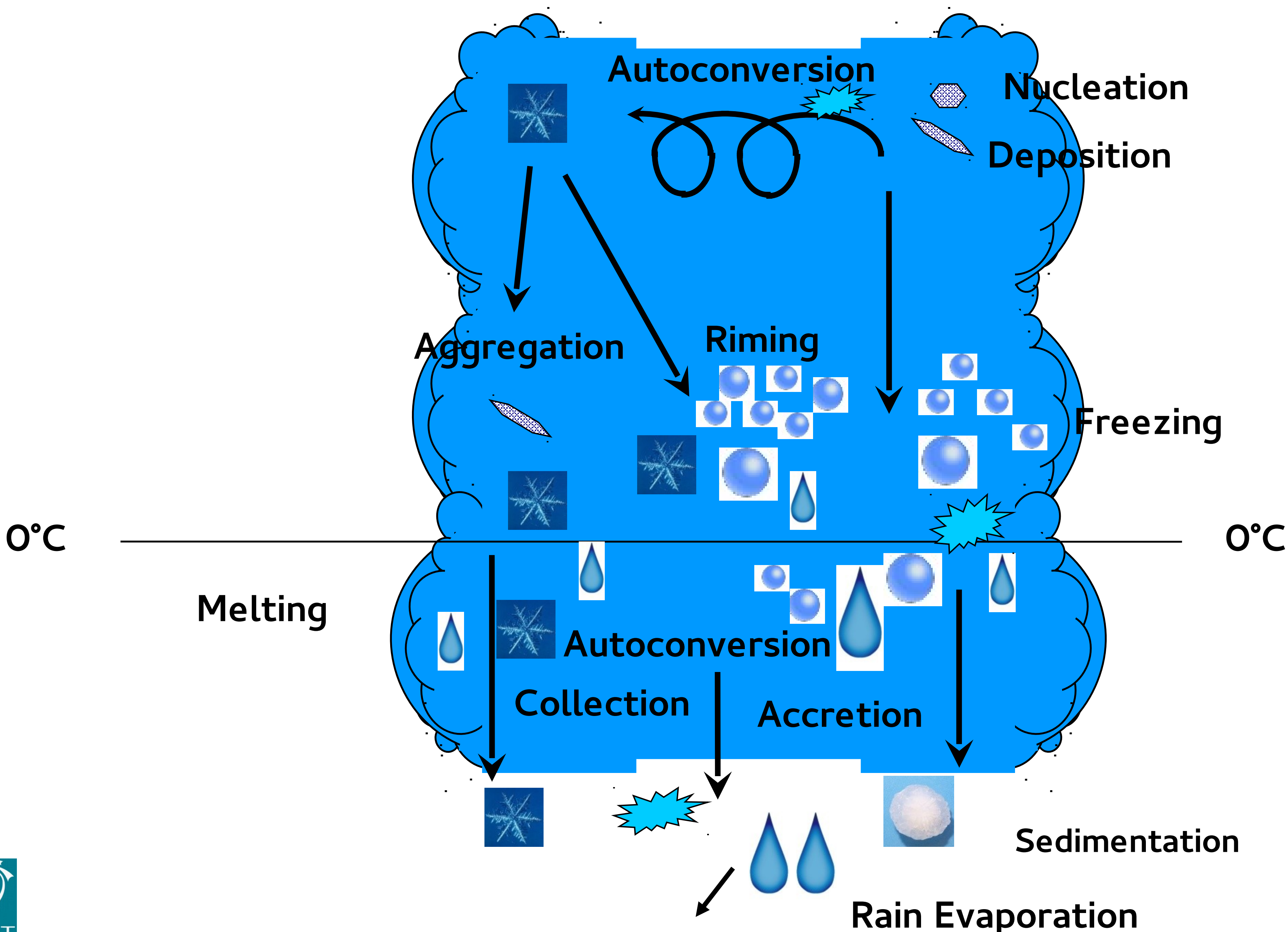
Computationally expensive

Extension to longer time ranges, 48-54h, so as to be in-line with deterministic forecast

Computationally more expensive

Perturbations of microphysical/turbulence time tendencies

Warm and cold rain process uncertainty

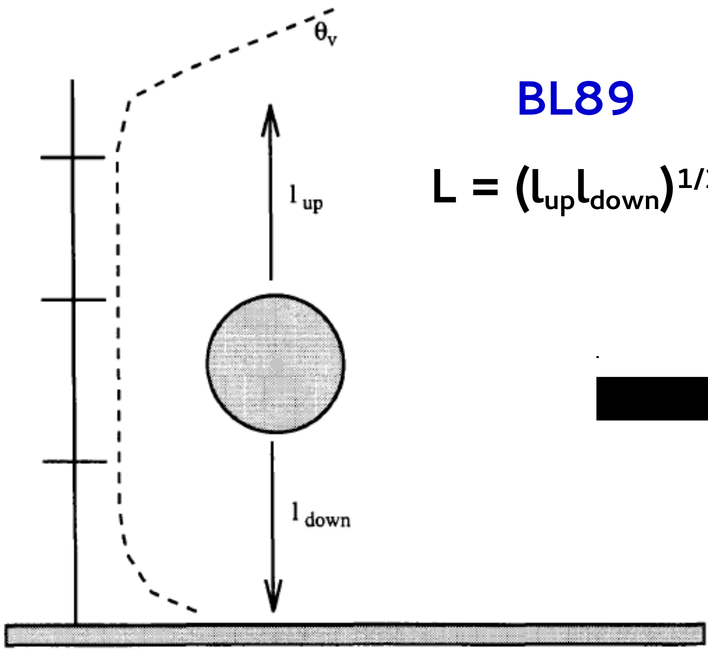


Turbulence Uncertainty

Turbulence parameterisation necessary unless simulating at very fine resolutions

Closure problem in Navier-Stokes equations → non-linear terms

Need closure scheme → Prandtl (1925), Deardoff (1980), Bougeault and Lacarrère (1989)



BL89

$L = (l_{up} l_{down})^{1/2}$

Value of L impacts turbulence flux definitions

X represents any state variable in 1D

$$\overline{u'_i X'} = c\, L \sqrt{e} \frac{\partial \bar{X}}{\partial x_i}$$

Turbulent flux of X

numerical constants

mixing length

Turbulence processes – Uncertainty?

Turbulent flux terms **approximation** to a complex reality

Parameterisation of flux terms a potential source of uncertainty

Microphysical process parameterisation uncertainty

Source and sink of each warm microphysical process perturbed by same factor

$$\left(\frac{\partial q_v}{\partial t}\right)_{mic} = + R_{evap}\,\mathrm{EVAP}$$

$$\left(\frac{\partial q_c}{\partial t}\right)_{mic} = - R_{auto}\,\mathrm{AUTO} - R_{acc}\,\mathrm{ACC}$$

$$\left(\frac{\partial q_r}{\partial t}\right)_{mic} = + R_{auto}\,\mathrm{AUTO} + R_{acc}\,\mathrm{ACC} - R_{evap}\,\mathrm{EVAP}$$

R_{evap}, R_{acc}, R_{auto} are random perturbation factors $\in$ **[0.5,1.5]**

Approach identical for cold processes

Turbulence process parameterisation uncertainty

Each turbulent flux term perturbed by same perturbing factor

$$\left(\frac{\partial \theta}{\partial t}\right)turb = R_{turb}\,\frac{\partial\left(uj'\theta'\right)}{\partial xi}$$

$$\left(\frac{\partial r_v}{\partial t}\right)turb = R_{turb}\,\frac{\partial\left(uj'r_v'\right)}{\partial xi}$$

$$\left(\frac{\partial u_i}{\partial t}\right)turb = R_{turb}\,\frac{\partial\left(uj'u_i'\right)}{\partial xi}$$

R_{turb} is a random perturbation factor $\in$ **[0.5,1.5]**

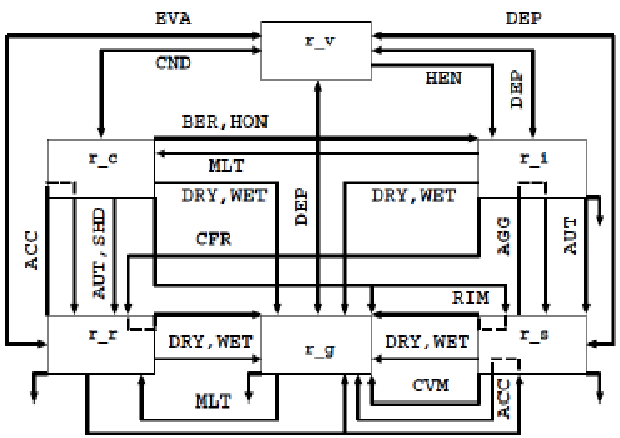
Meso-NH
mesoscale non-hydrostatic model

Non-Hydrostatic Model, Eulerian system of eqns.

Microphysics follow ICE3 (Pinty et Jabouille 1998)

Turbulence follows Cuxart et al. (2000)

ICE3



6 water species

1 moment scheme

Gamma-law and MP distributions

Kessler (1969) warm

Cold based on Lin et al. (1983)

Turbulence

$$\overline{u_i'\theta'} = -\frac{2}{3}\frac{L}{C_s}e^{\frac{1}{2}}\frac{\partial\overline{\theta}}{\partial x_i}\phi_i,$$

$$\overline{u_i'r_v'} = -\frac{2}{3}\frac{L}{C_h}e^{\frac{1}{2}}\frac{\partial\overline{r_v}}{\partial x_i}\psi_i,$$

$$\overline{u_i'\,u_j'} = \frac{2}{3}\delta_{ij}\,e - \frac{4}{15}\frac{L}{C_m}e^{\frac{1}{2}}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_m}{\partial x_m}\right),$$

$$\overline{\theta' r_v'} = C_2 L^2\left(\frac{\partial\overline{\theta}}{\partial x_m}\frac{\partial\overline{r_v}}{\partial x_m}\right)(\phi_m + \psi_m),$$

3D scheme for LES

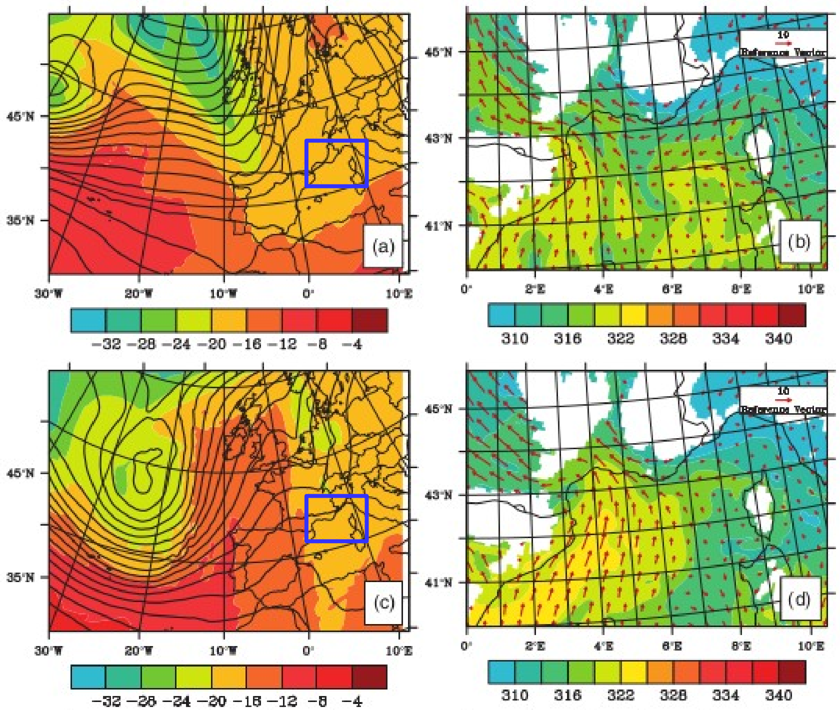
1D ignoring horizontal

L follows **BL89**

TKE prognosed

Case Studies

4 cases of heavy precipitation in south–eastern France: 1st to 4th November 2011



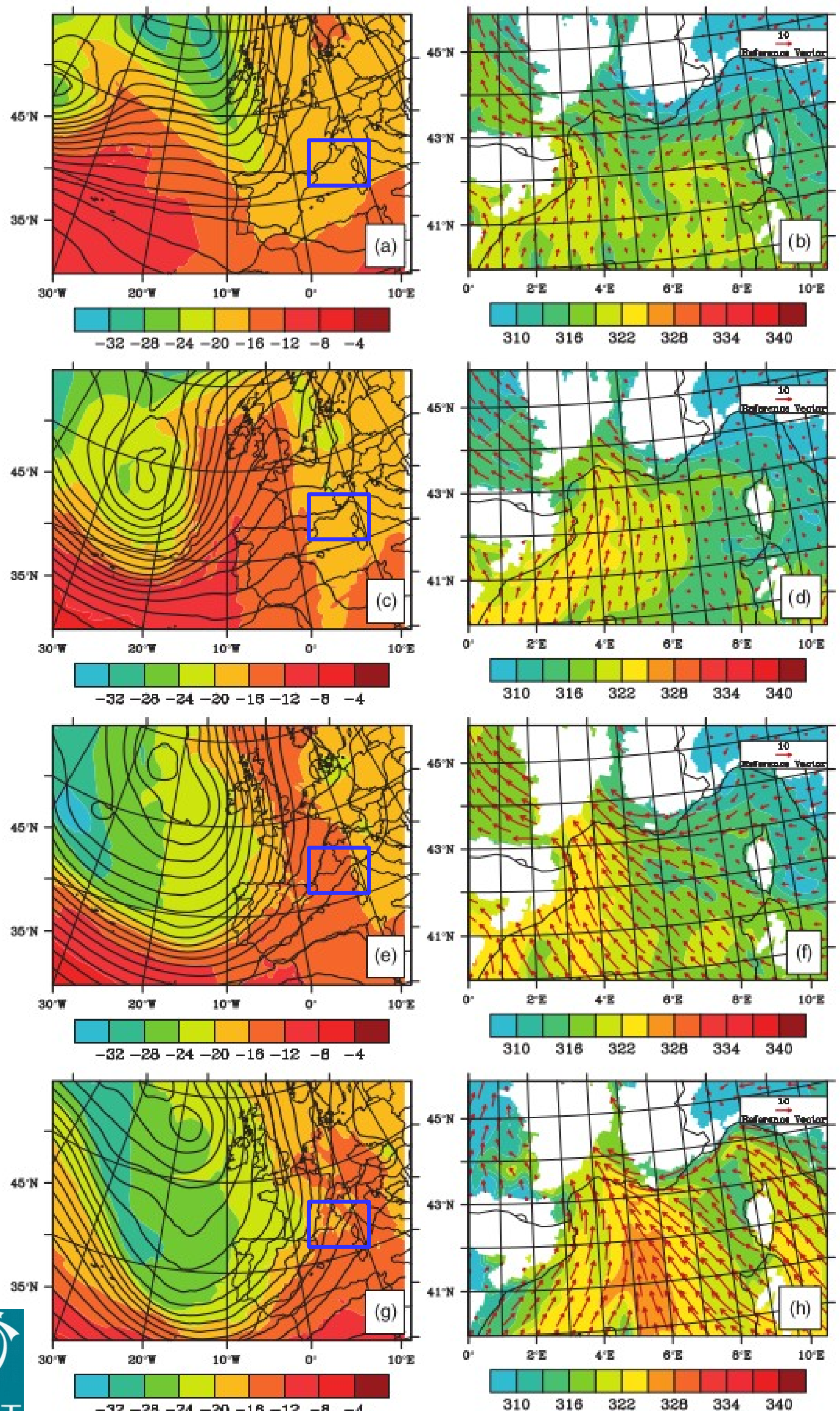
1st and 2nd Moderate to weak low-level flow

Precipitation observed on plains

MET éireann

Case Studies

4 cases of heavy precipitation in south–eastern France: 1st to 4th November 2011



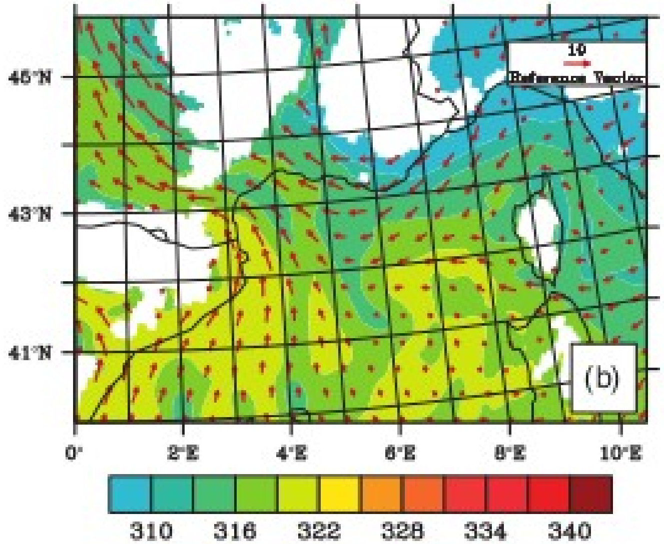
1st and 2nd Moderate to weak low-level flow

Precipitation observed on plains

3rd and 4th Strong low-level flow

Precipitation observed on orography

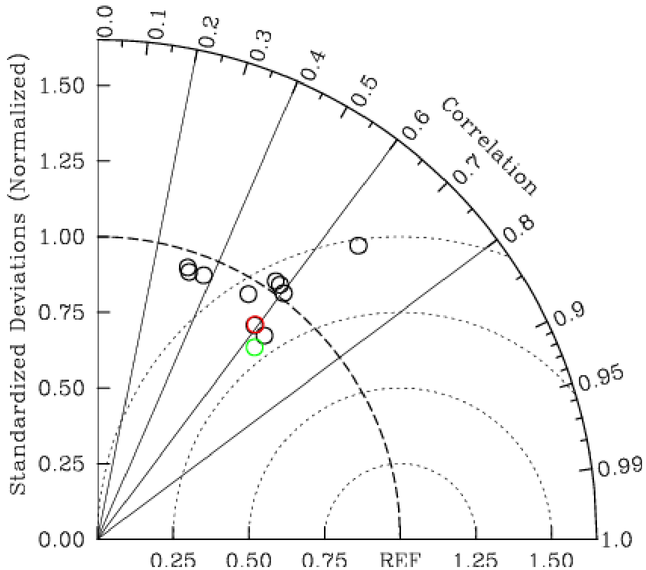
Potential usefulness of microphysics/turbulence perturbations

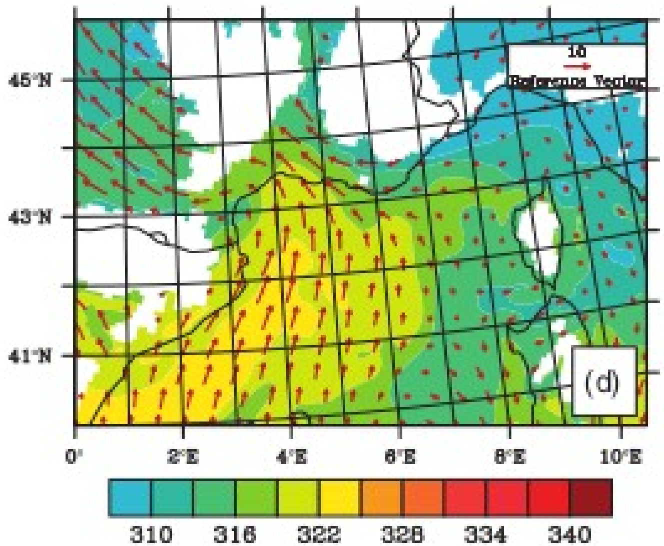


1[st] Nov

Weak to moderate flow →

Precipitation on plains

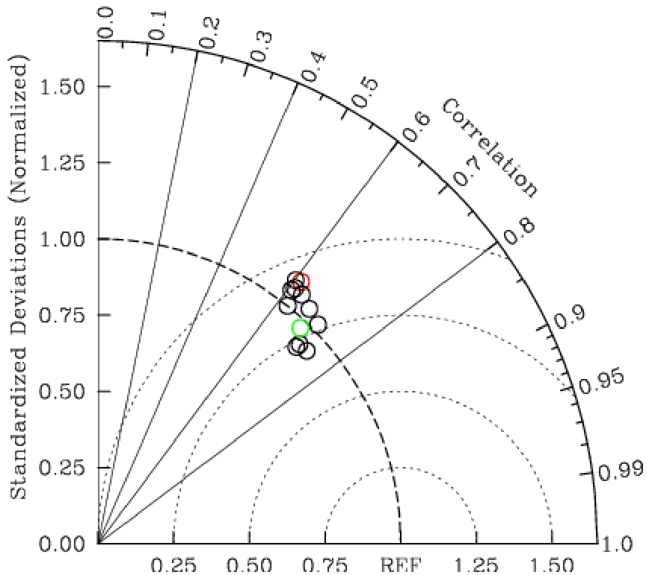




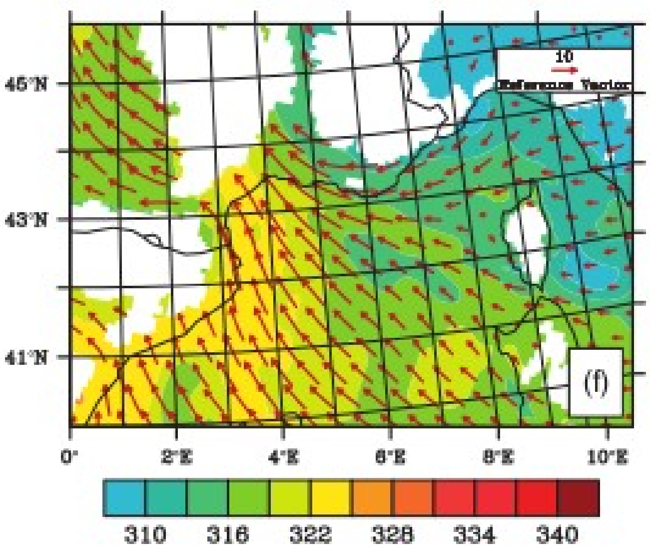
2[nd] Nov

Weak to moderate flow →

Precipitation on plains



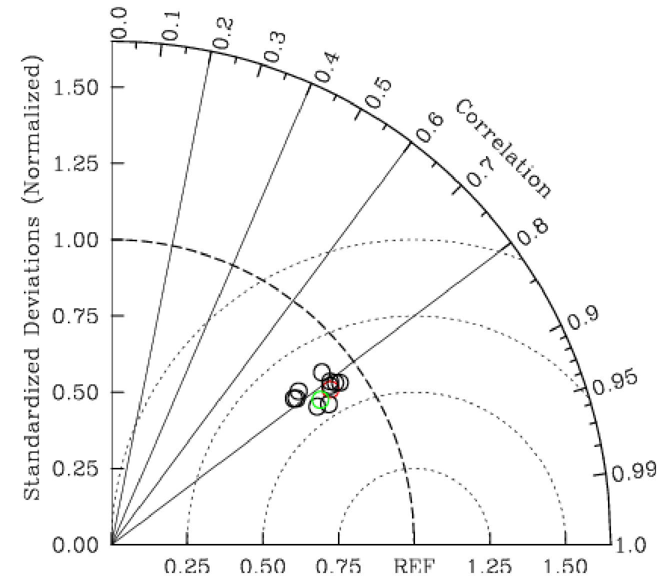
Potential usefulness of microphysics/turbulence perturbations

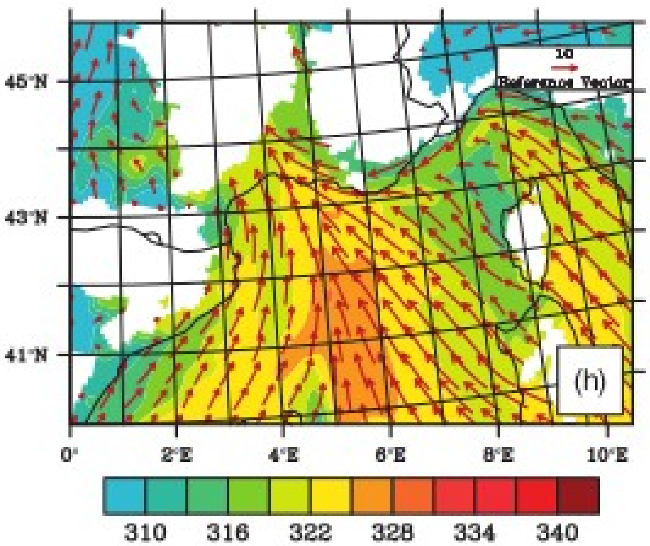


3rd Nov

Strong flow →

Precipitation on orography

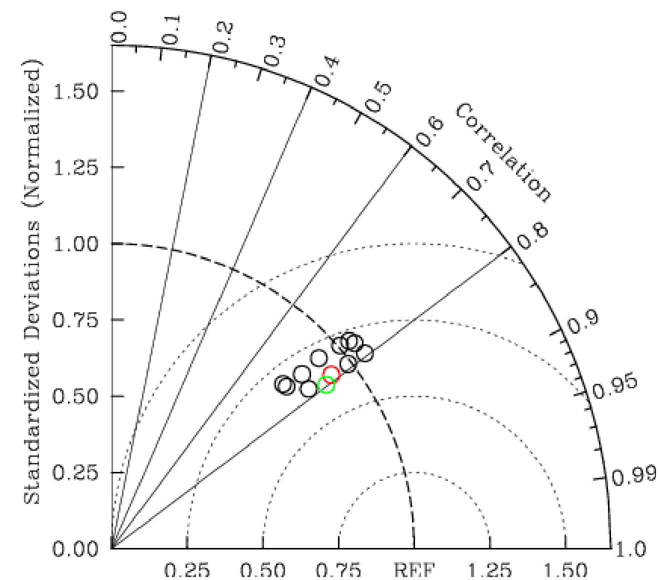




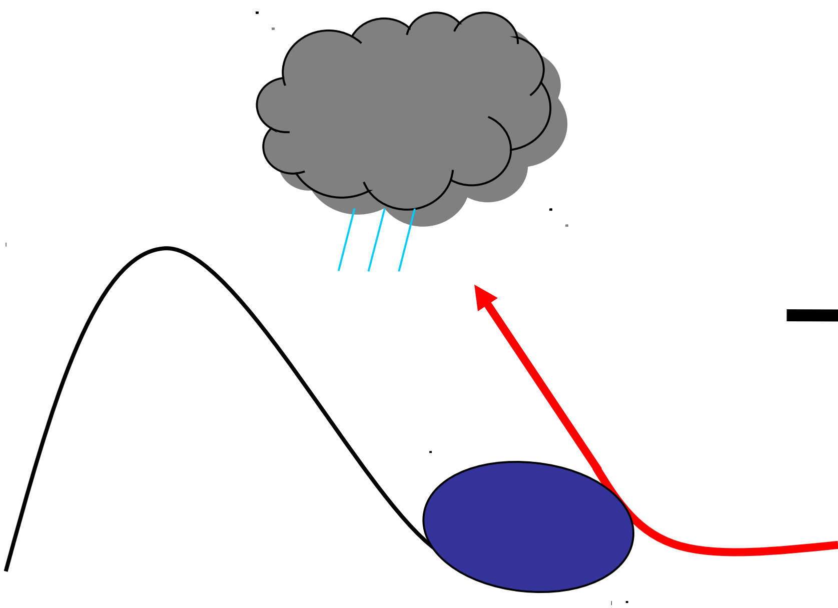
4th Nov

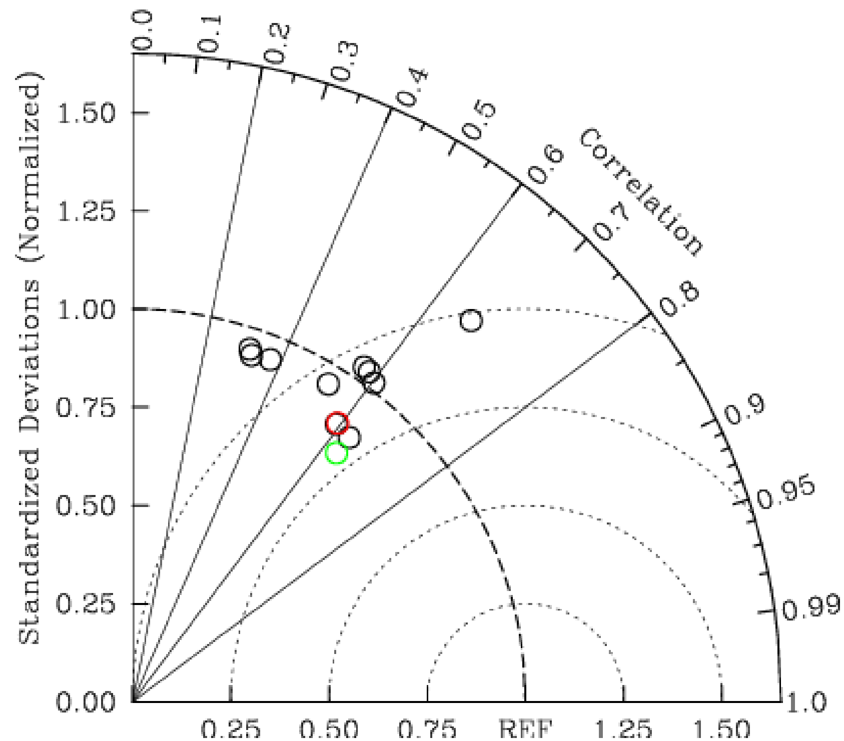
Strong flow →

Precipitation on orography



Potential usefulness of microphysics/turbulence perturbations



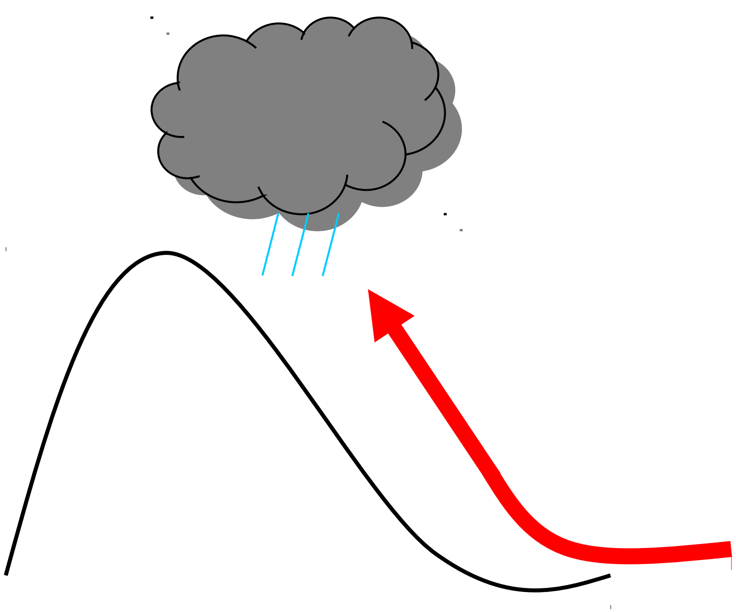


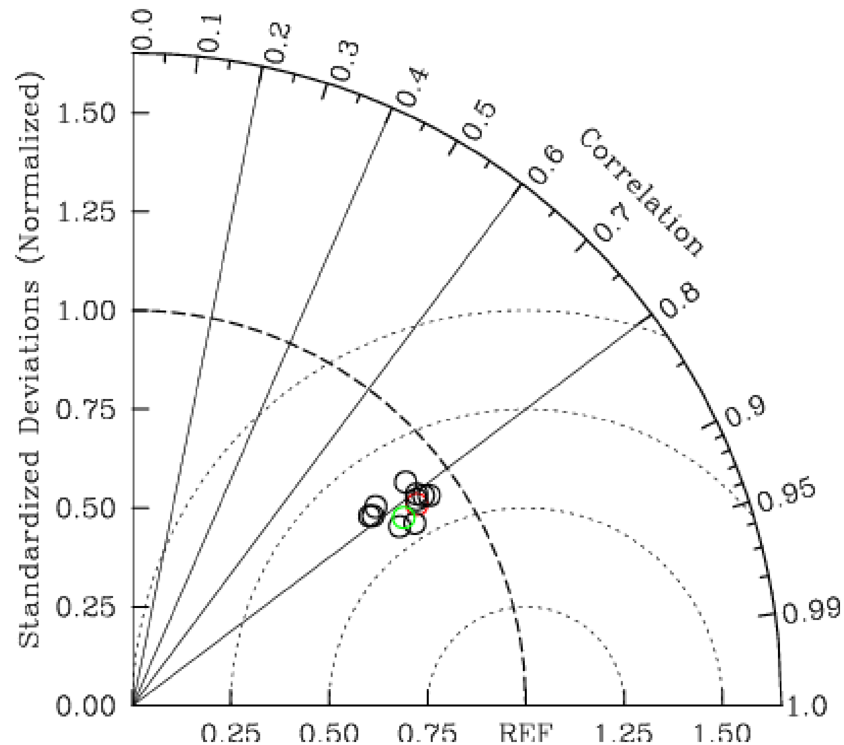
Weak low-level flow
Convection sustained by **low–level cold pool**

Lower model skill and thus **moderate** dispersion when perturbing physical processes

Hally et al. (2013) QJRMS

Potential usefulness of microphysics/turbulence perturbations



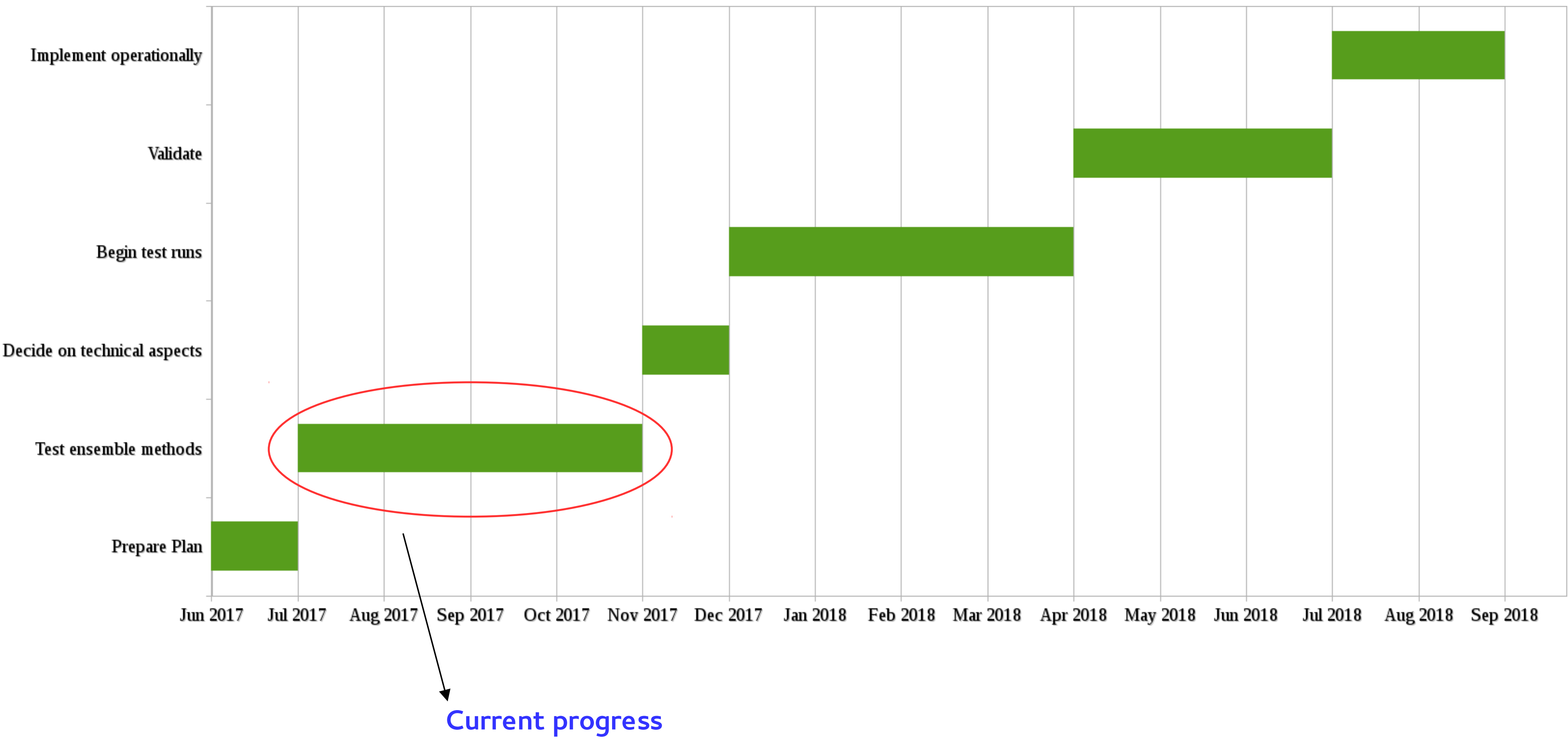


Strong low-level flow
Convective initiation by **orography**

High model skill and thus **low** dispersion when perturbing physical processes

Hally et al. (2013) QJRMS

Implementation plan

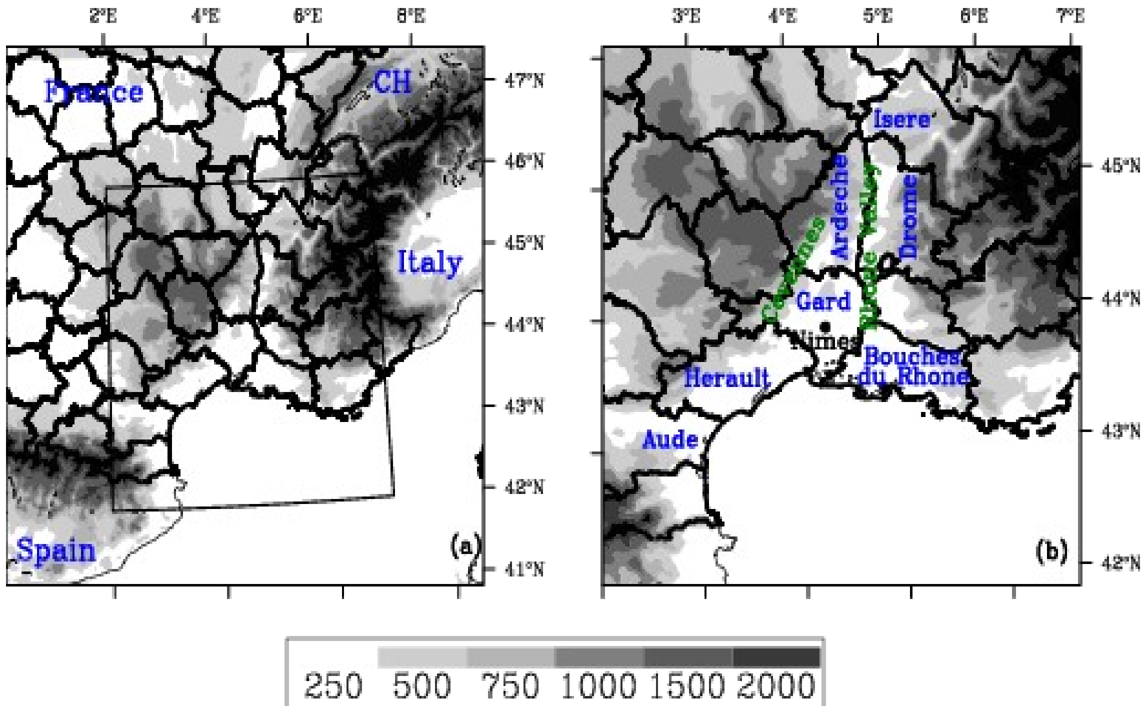


The Irish Regional Ensemble (IRE): Development of a convection-permitting Ensemble Prediction System at Met Éireann

Alan Hally, Rónán Darcy, Colm Clancy, Eoin Whelan

Shedding light on the greyzone, 13th – 16th Nov. 2017, ECMWF, Reading

Simulation set-up



From Hally et al. (2013), QJRMS

For each case study →

- **1** CTRL Run (ICE3, Cuxart et al. (2000) 1D, BL89)
- **AROME** analyses Initial and Boundary conditions
- **10** Perturbed Members for Ensembles
- **2.5km** resolution

Example SLAF set-up

$$IC_m = A_c + (+/-K_m)*(IFS_0 - IFS_{N-6})$$

$$BC_m = IFS_0 + (+/-K_m)*(IFS_N - IFS_{N-6})$$

SLAF example for default setup (constant 6h lag) - showing data used from HRES
Example for HarmonEPS 10+1 members, +36h forecast from **2016052006**

Member	FC length: +0	FC length: +3	----	FC length: +36
Mbr 0 SLAFLAG=0 SLAFDIFF=0 K_m=0	A_c=2016052006 IFS_0=2016052000 +6	IFS_0=2016052000 +9	---	IFS_0=2016052000 +42
Mbr 1 SLAFLAG=6 SLAFDIFF=6 K_m=1.75	IFS_N=2016051918 +12 IFS_N-6=2016052000 +6	IFS_N=2016051918 + 15 IFS_N-6=2016052000 +9	---	IFS_N=2016051918 +48 IFS_N-6=2016052000 +42
Mbr 2 SLAFLAG=6 SLAFDIFF=6 K_m=-1.75	IFS_N=2016051918 +12 IFS_N-6=2016052000 +6	IFS_N=2016051918 +15 IFS_N-6=2016052000 +9	---	IFS_N=2016051918 +48 IFS_N-6=2016052000 +42
Mbr 3 SLAFLAG=12 SLAFDIFF=6 K_m=1.5	IFS_N=2016051912 +18 IFS_N-6=2016051918 +12	IFS_N=2016051912 +21 IFS_N-6=2016051918 +15	---	IFS_N=2016051912 +54 IFS_N-6=2016051918 +48
Mbr 4 SLAFLAG=12 SLAFDIFF=6 K_m=-1.5	IFS_N=2016051912 +18 IFS_N-6=2016051918 +12	IFS_N=2016051912 +21 IFS_N-6=2016051918 +15	---	IFS_N=2016051912 +54 IFS_N-6=2016051918 +48
Mbr 5 SLAFLAG=18 SLAFDIFF=6 K_m=1.2	IFS_N=2016051906 +24 IFS_N-6=2016051912 +18	IFS_N=2016051906 +27 IFS_N-6=2016051912 +21	---	IFS_N=2016051906 +60 IFS_N-6=2016051912 +54
Mbr 6 SLAFLAG=18 SLAFDIFF=6 K_m=-1.2	IFS_N=2016051906 +24 IFS_N-6=2016051912 +18	IFS_N=2016051906 +27 IFS_N-6=2016051912 +21	---	IFS_N=2016051906 +60 IFS_N-6=2016051912 +54
Mbr 7 SLAFLAG=24 SLAFDIFF=6 K_m=1.0	IFS_N=2016051900 +30 IFS_N-6=2016051906 +24	IFS_N=2016051900 +33 IFS_N-6=2016051906 +27	---	IFS_N=2016051900 +66 IFS_N-6=2016051906 +60
Mbr 8 SLAFLAG=24 SLAFDIFF=6 K_m=-1.0	IFS_N=2016051900 +30 IFS_N-6=2016051906 +24	IFS_N=2016051900 +33 IFS_N-6=2016051906 +24	---	IFS_N=2016051900 +66 IFS_N-6=2016051906 +60
Mbr 9 SLAFLAG=30 SLAFDIFF=6 K_m=0.9	IFS_N=2016051818 +36 IFS_N-6=2016051900 +30	IFS_N=2016051818 +39 IFS_N-6=2016051900 +33	---	IFS_N=2016051818 +72 IFS_N-6=2016051900 +66
Mbr 10 SLAFLAG=30 SLAFDIFF=6 K_m-0.9	IFS_N=2016051818 +36 IFS_N-6=2016051900 +30	IFS_N=2016051818 +39 IFS_N-6=2016051900 +33	---	IFS_N=2016051818 +72 IFS_N-6=2016051900 +66