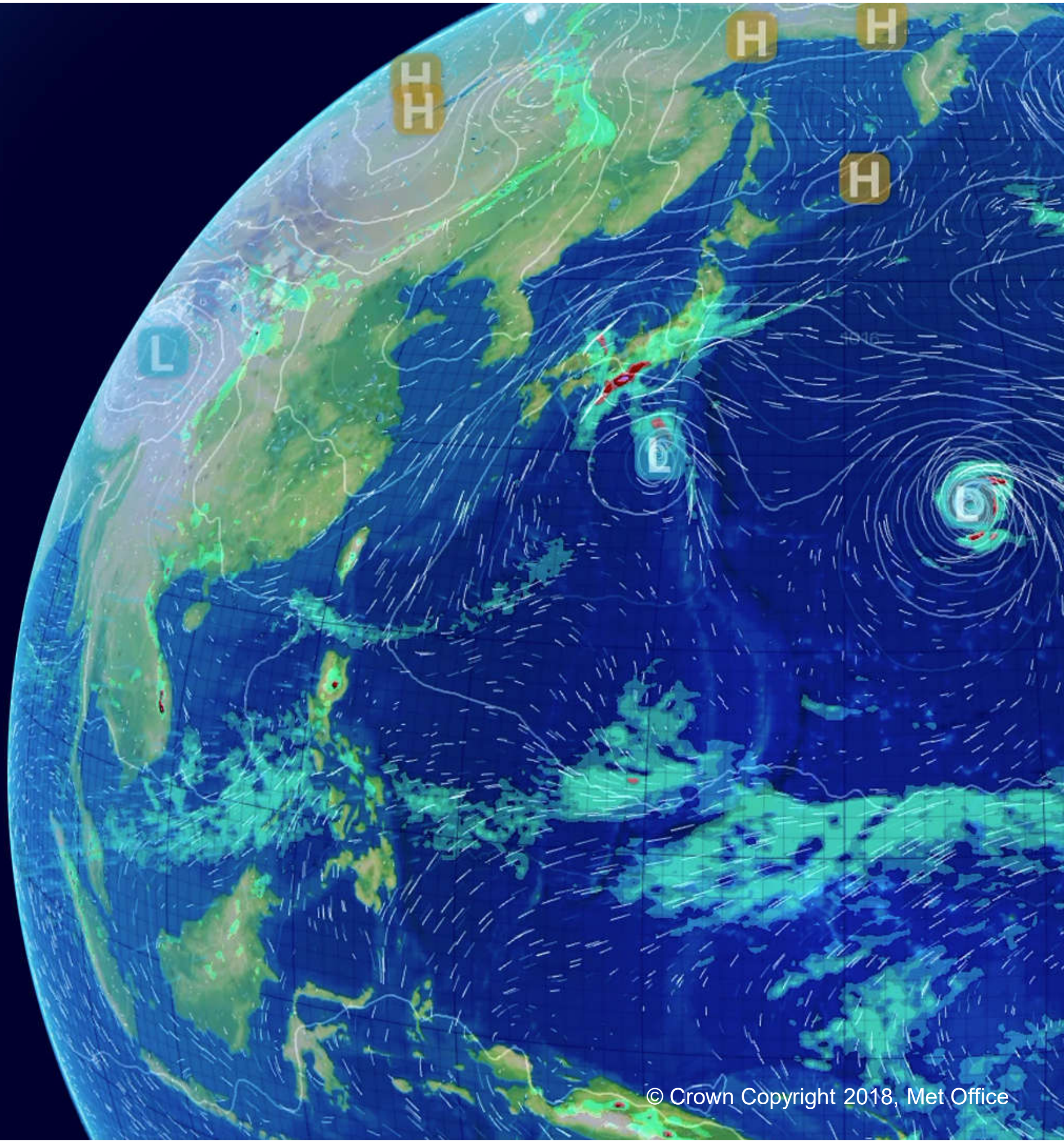
Met Office

Developments in the Met Office hourly 4D-Var system

Bruce Macpherson



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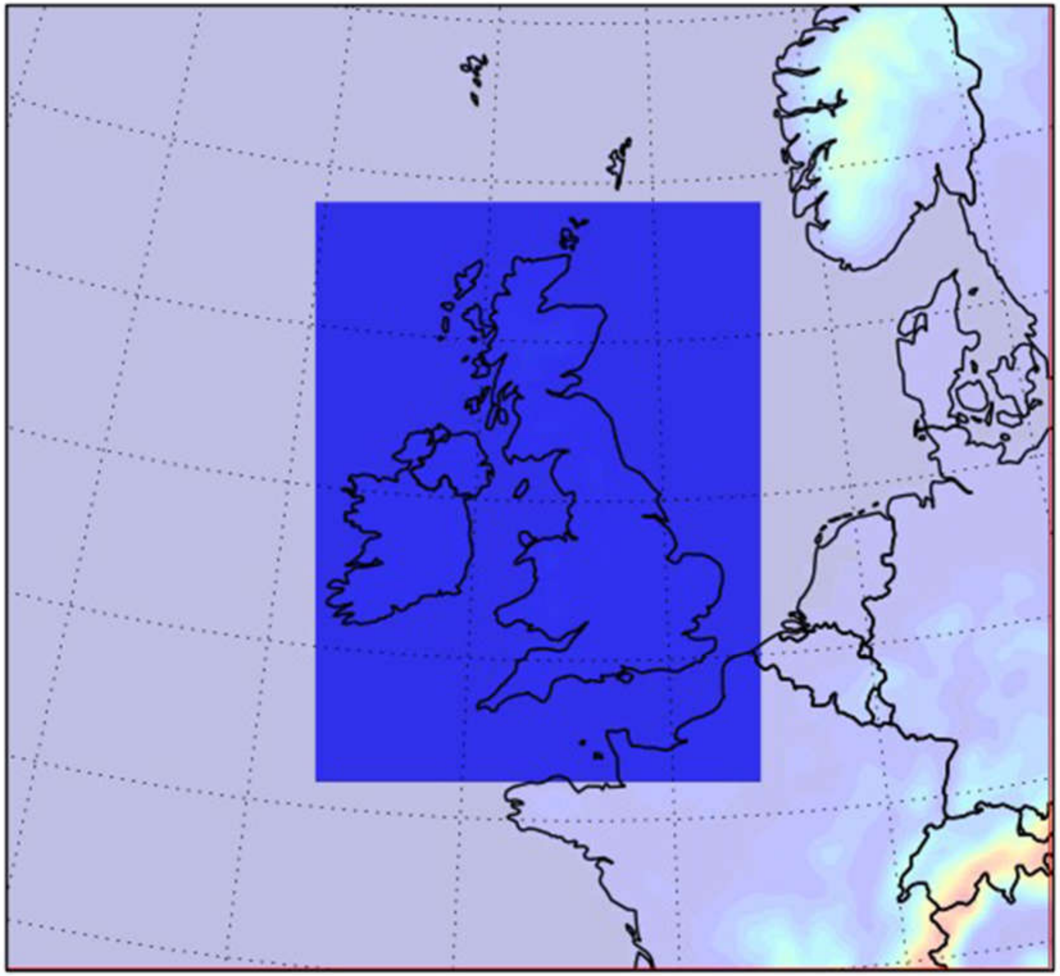
UKV model



1.5km fixed resolution

1.5→4km variable resolution

• 70 vertical levels

• top ~40km

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UKV model cycling and forecasts

- **24 hourly assimilation cycles per day**
  - Observation cut-off 45min (***but 80min at 11 & 23 UTC for sondes***)
  - Linear PF model at 4.5km resolution for stability and cost
- **Forecasts:**
  - → t+12 every hour,
  - → t+54 every 3 hours,
  - → t+120 from DT 03, 15 UTC
- **Lateral boundaries from 00, 06, 12, 18 UTC runs of Global model**

‘Nowcasting’ advantage of hourly 4DVAR

- 3-hourly → hourly cycles
- 75 min → 45 min observation cut-off
- HPC resources ↑
- → Average lead time reduction of 2 hours in NWP input to post-processing systems

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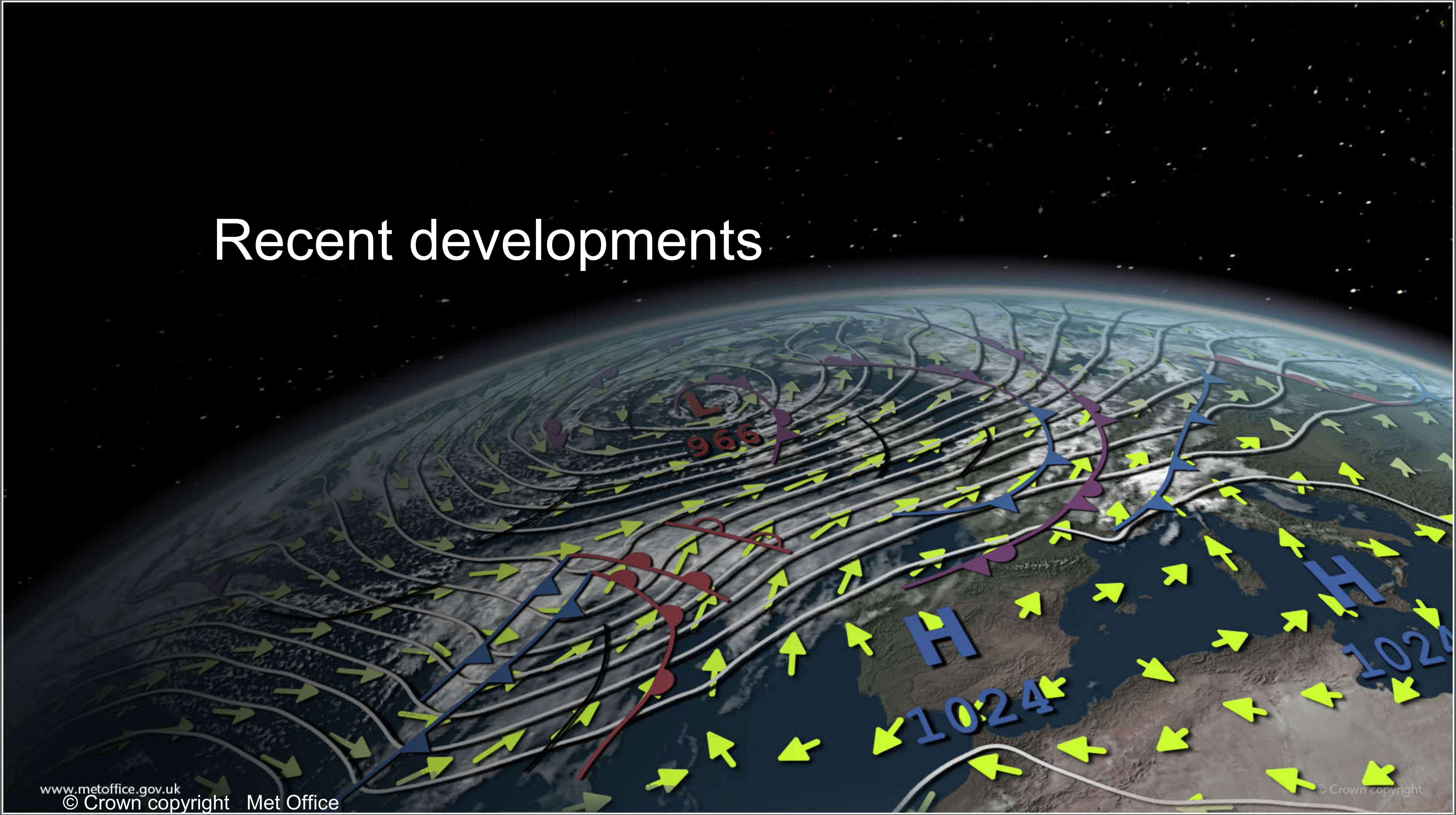
UKV - extra observations **not** assimilated in global model data assimilation

- **GeoCLOUD cloud fraction profiles (hourly, 12km thinning)**
- **Cloud fraction profiles from SYNOPs (hourly)**
- **Radar-derived surface rain rate (15min, 5km resolution)**
- **Doppler radial winds from 16 UK radars (10min)**
- **AMVs from NWC SAF (hourly)**
- **T2m & RH2m from roadside sensors (hourly)**
- **Visibility from SYNOPs, METARs and *roadside* (hourly)**

Recent developments



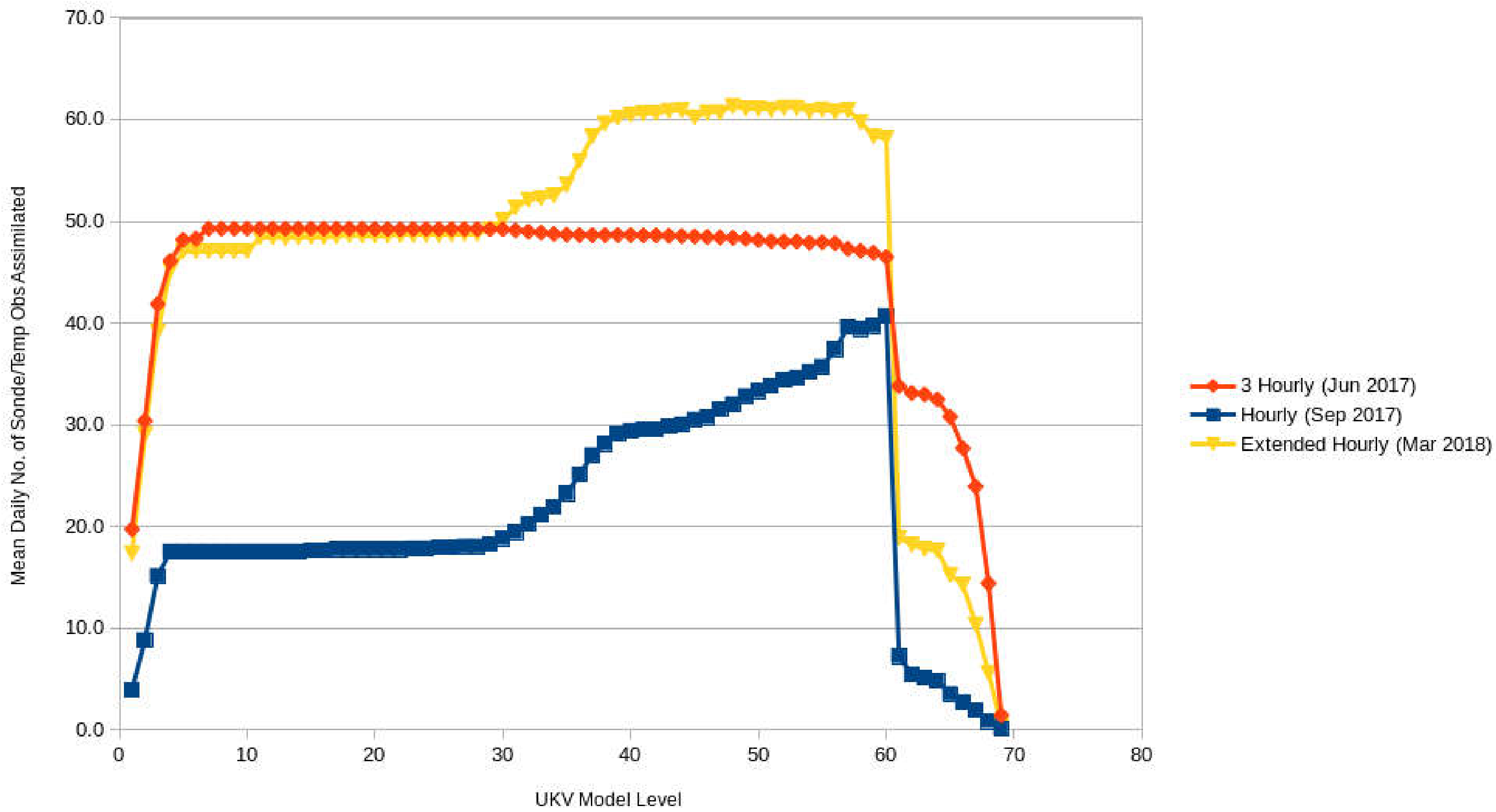
Met Office Radiosonde recovery in hourly cycle

Daily reports assimilated in UKV

hourly cycle

extended 11/23 UTC cut-off

3-hourly cycle



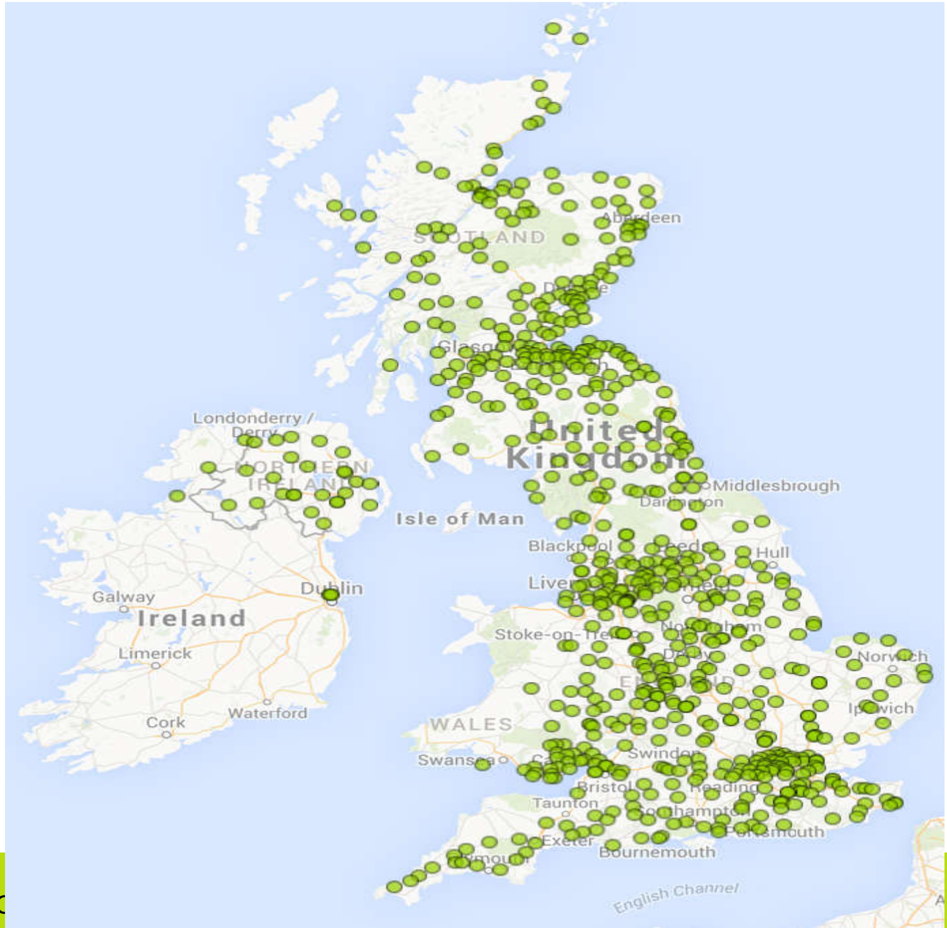
~3km ~15km

Model level →

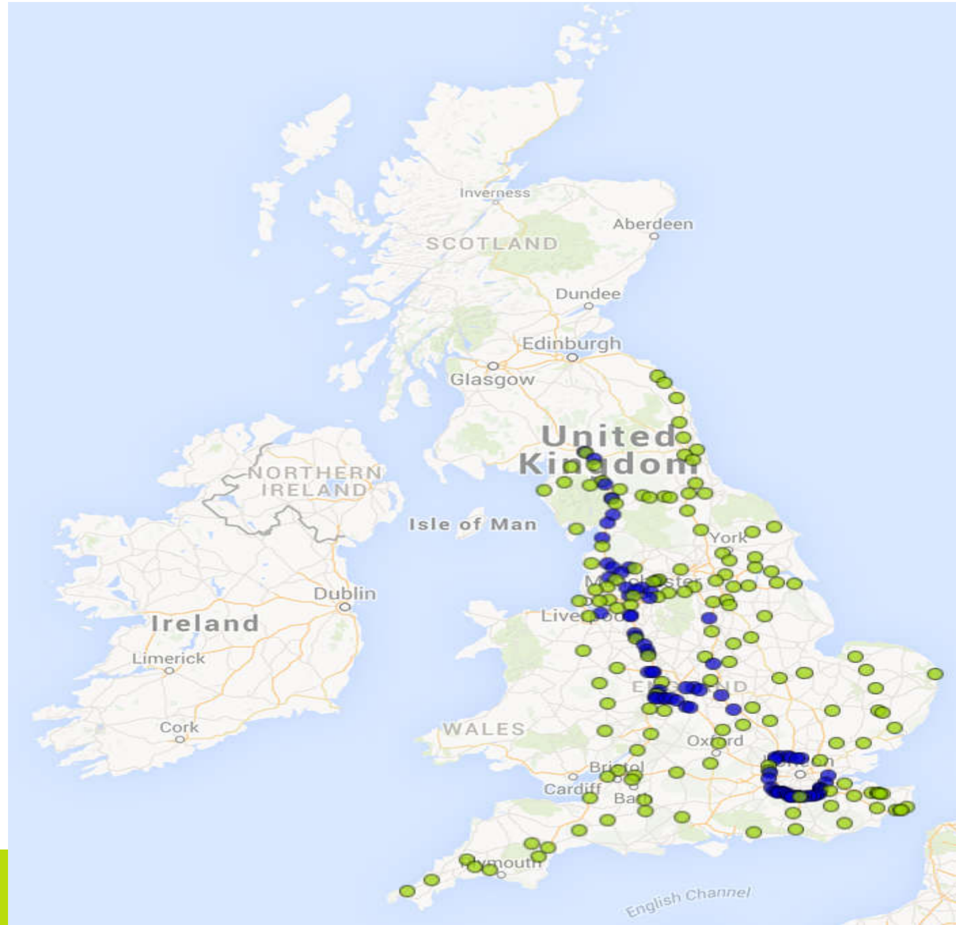
Gareth Dow

Roadside sensor network

T_{2m} / RH_{2m} (*reductions*)



Visibility (*now operational*)



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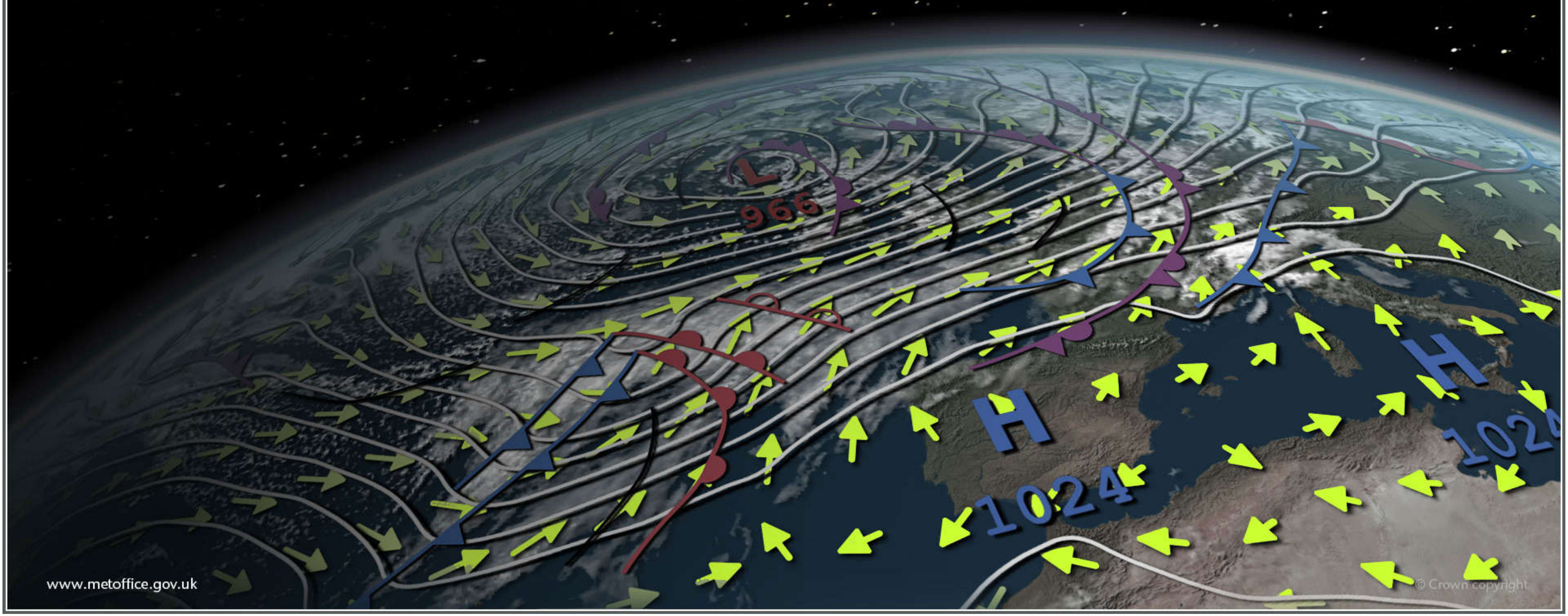
Forthcoming changes (operational in Spring 2019)



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Moisture incrementing Operator (MIO)

Marco Milan

Summary of MIO

- Humidity control variable in VAR is function of RH_{total}.
- Older versions of MIO led to spin-up in precipitation.
- In operational UKV a 'bypass version' is used,
  - $q' = q_T'$
  - q_{cl}' and q_{cf}' develop as model evolves
- MIO subdivides q_T' into q', q_{cl}' and q_{cf}' based on the cloud fraction (liquid C_l and frozen C_f).
- Increments are adjusted using statistics of perturbations from MOGREPS-UK ensemble (function of RH_{total} and vertical level).

Met Office Theory of MIO (Migliorini et al., 2018)

1. Increments in cloud water content are derived as:

$$q'_{cl} = C_l\left(q'_T - q'_{cf} - q'_s\right) \simeq C_l\left(q'_T - q'_{cf} - q_s\frac{\partial ln(e_s)}{\partial T}T'\right)$$

2. Similar approach for cloud ice content gives:

$$q'_{cl} \simeq \frac{C_l\left(1 - C_f\right)}{1 - C_l C_f}\left(q'_T - q_s\frac{\partial ln(e_s)}{\partial T}T'\right)$$

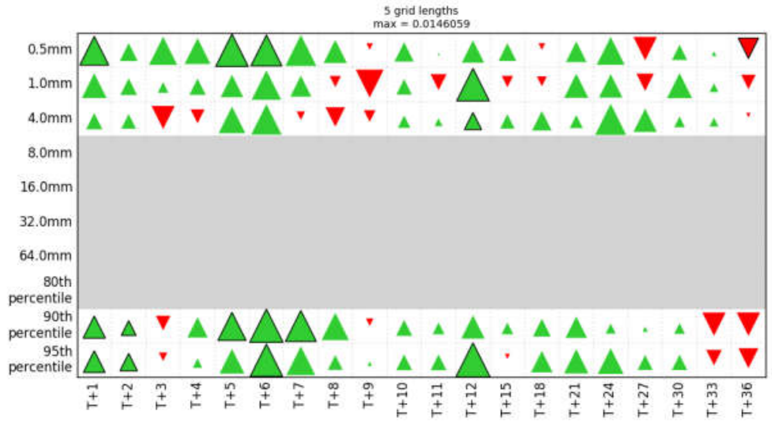
3. Linear regression between ensemble perturbations and theoretical values provides coefficients. For every model level we compute 22 coefficients relative to RH_{total} (RH divided in bins of 5%).

4. When MIO is applied, the increments are adjusted using the pre-computed coefficients.

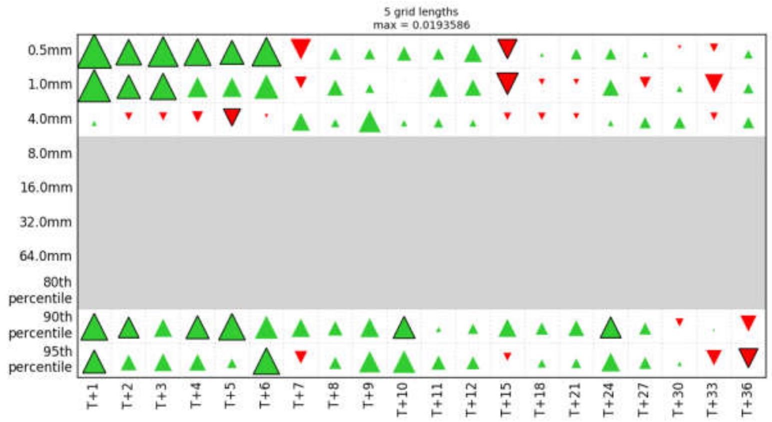
MIO impacts

- Statistics over ~ 50 days in Winter 2017-2018 and Summer 2017.
- Comparison between runs with and without MIO.
- Positive impact on precipitation scores.
  - Mostly for short-period and in winter.
- Other variables: impact relatively neutral. T_{2m} slightly worse in Summer, but better in Winter.

SUMMER FSS

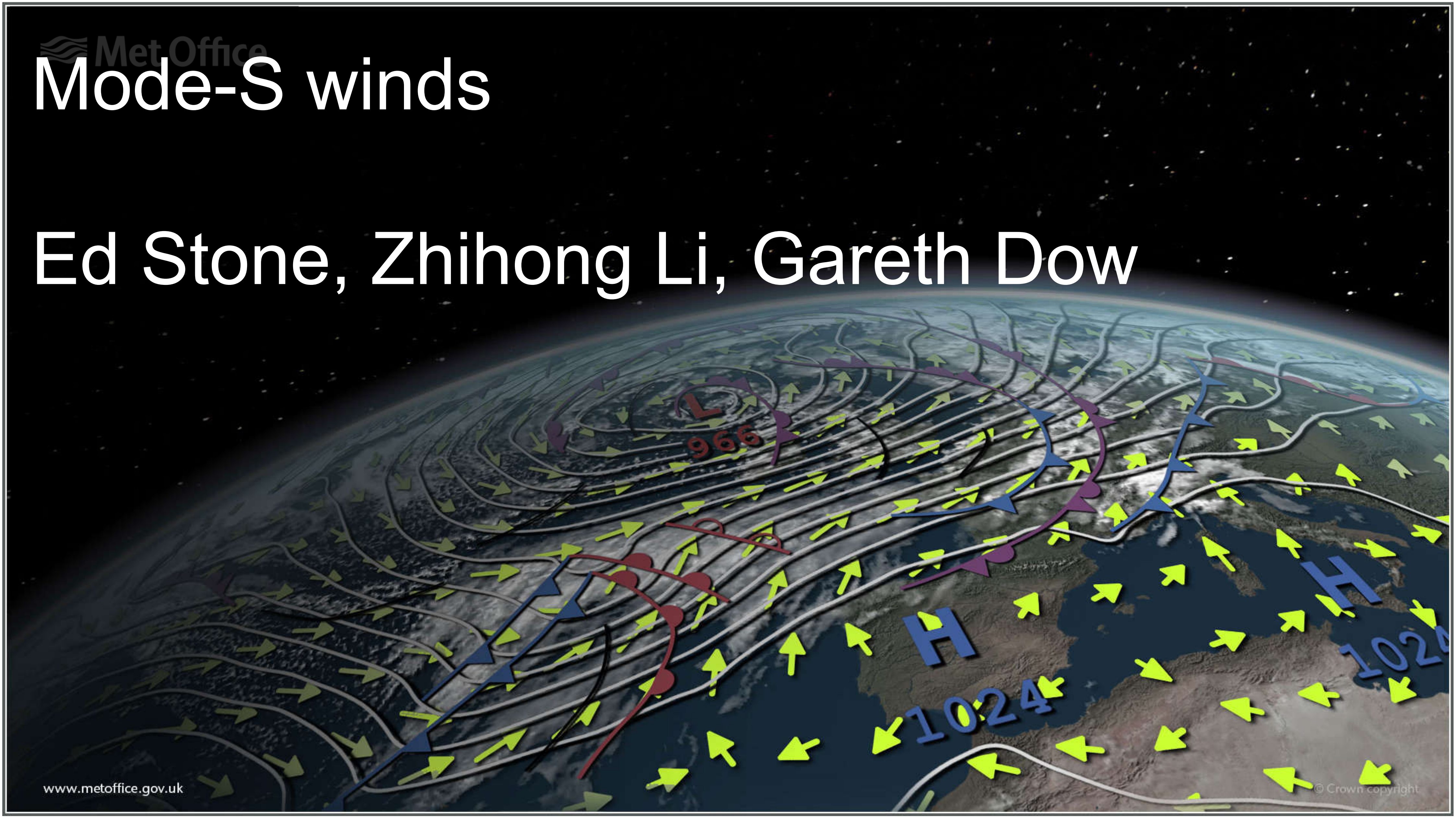


WINTER FSS



Mode-S winds

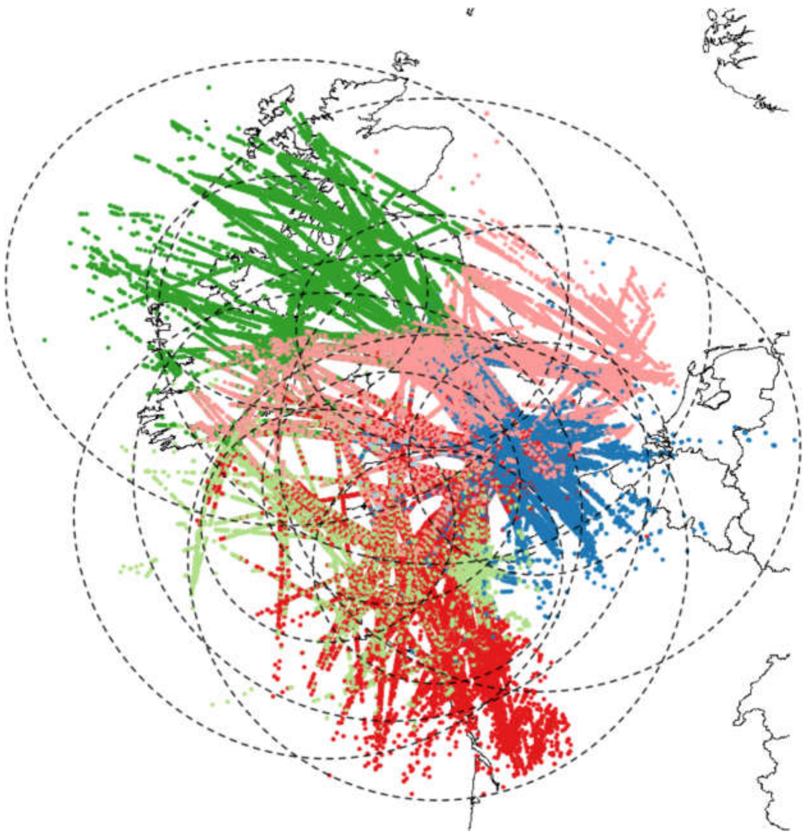
Ed Stone, Zhihong Li, Gareth Dow



Current Mode-S coverage

6 receivers

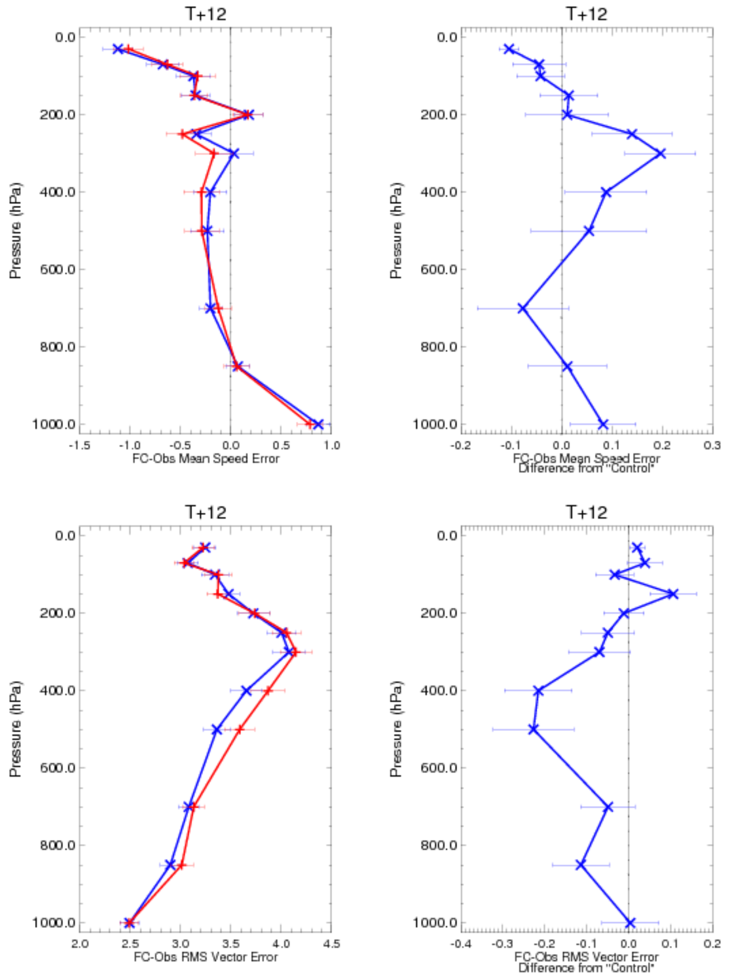
~6 million obs per day



Verification of winds v Sondes (1/07/2017 -15/08/17) T+12

Mean speed

Vector Wind



Error

Difference from Control

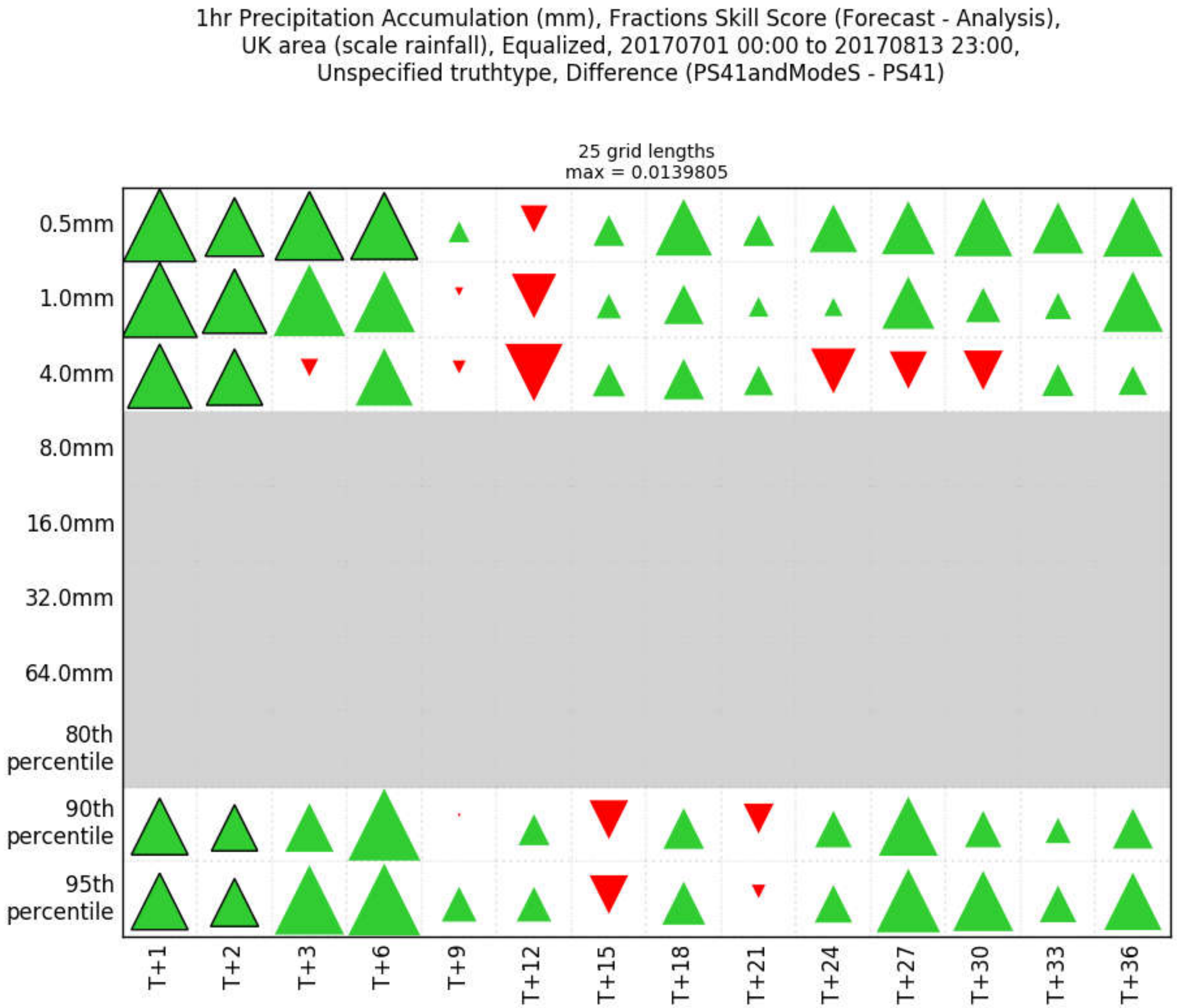
Control

Control+ Mode-S

(Winds only, 4.5km, 40hPa thinning, 10min obs)

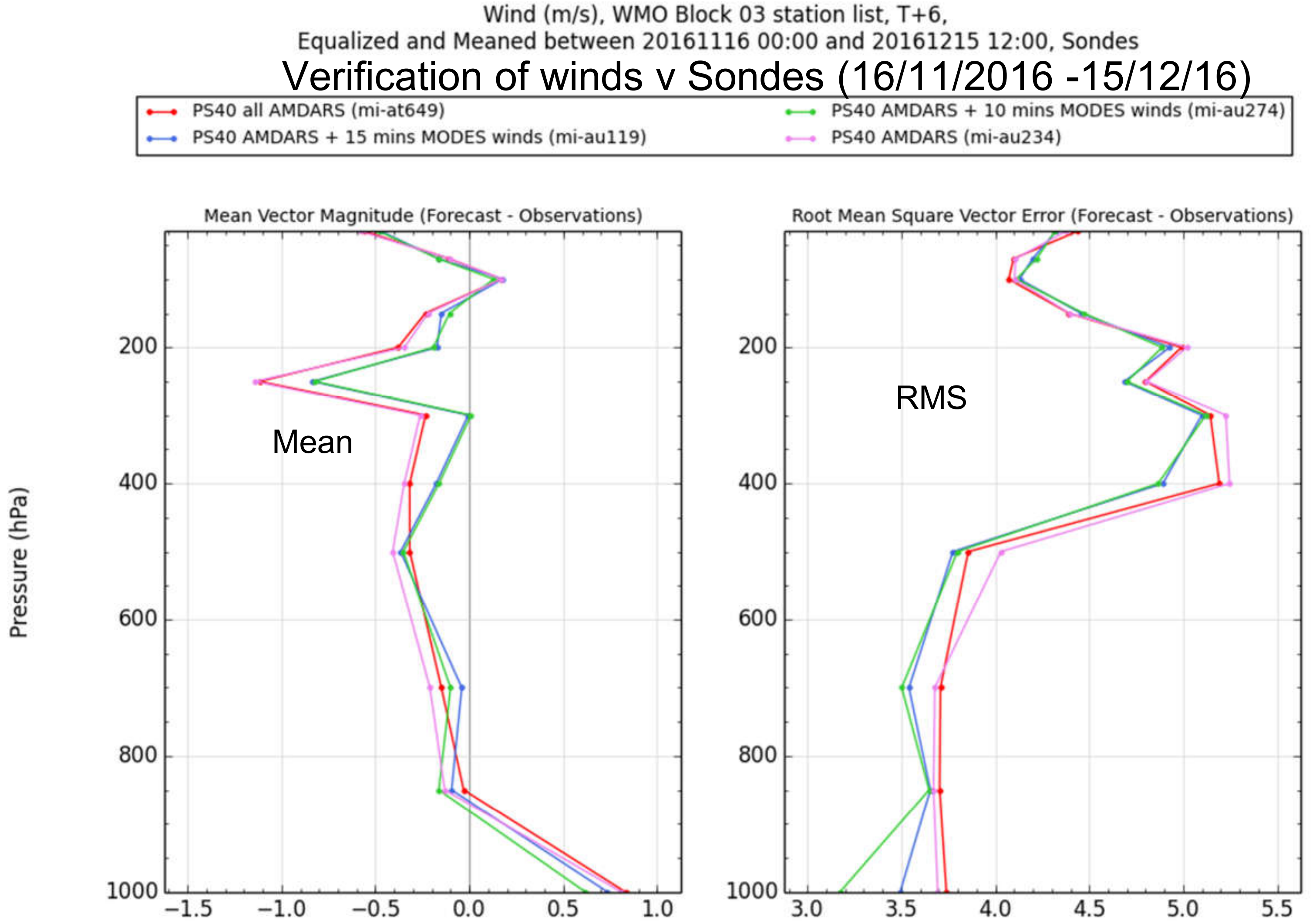
FSS of 1 hr precipitation accumulation (01/07/2017 – 13/08/2017)

Impact of Mode-S



Verification of winds v Sondes (16/11/2016 -15/12/16)

T+6



Red: all AMDARS, NO Mode-S
Purple: half AMDARS, NO Mode-S
Blue: half AMDARS + 15min Mode-S
Green: half AMDARS + 10min Mode-S

Mode-S with reduced AMDARS

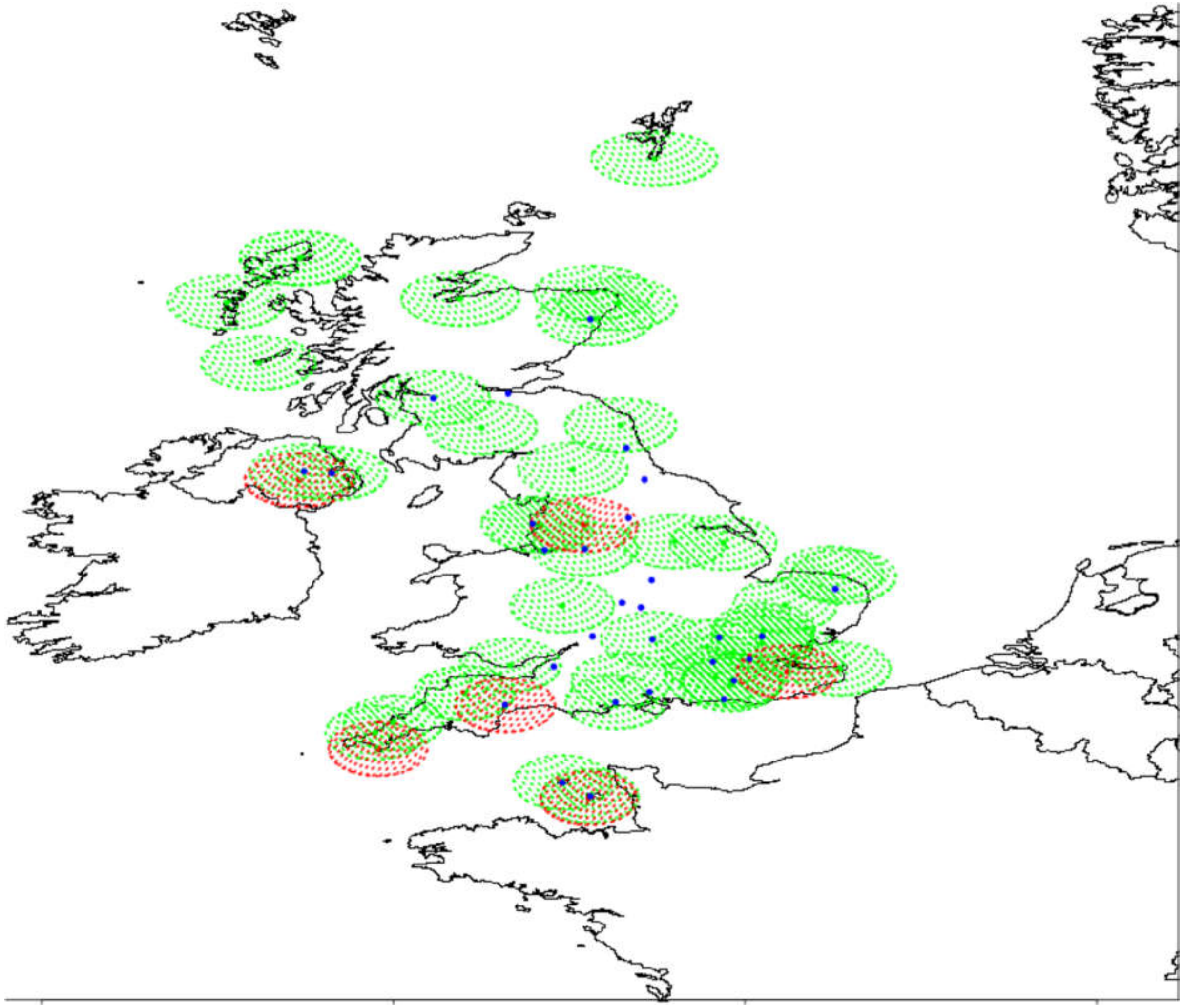
Current Mode-S network

Met Office

ATC radar

Mode-S receiver

Airport



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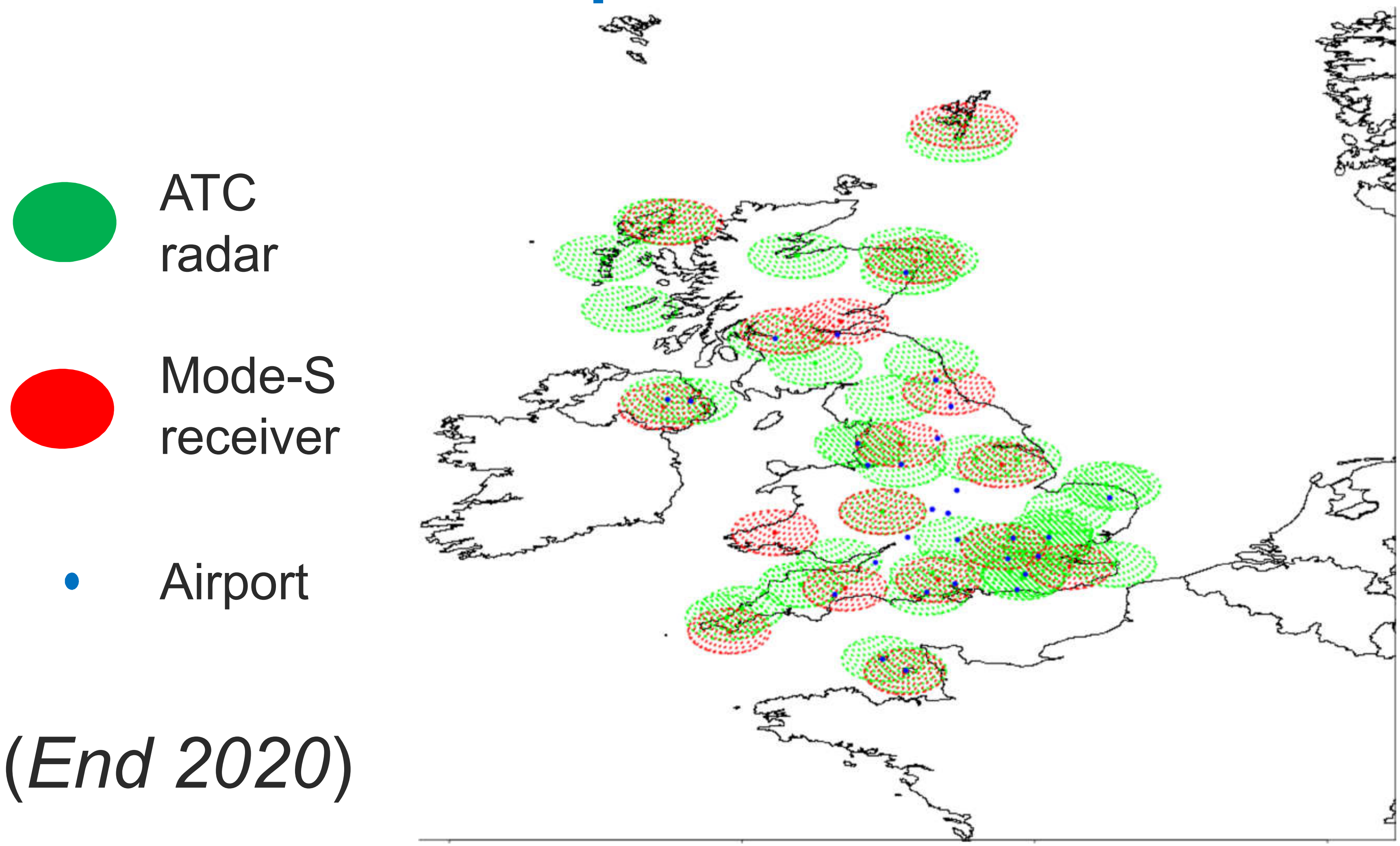
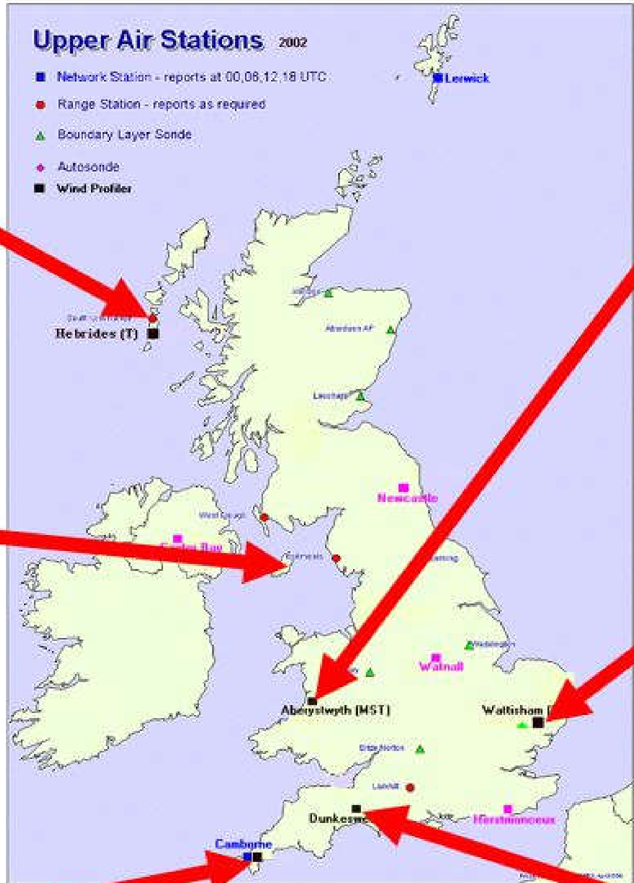
Proposed Mode-S network



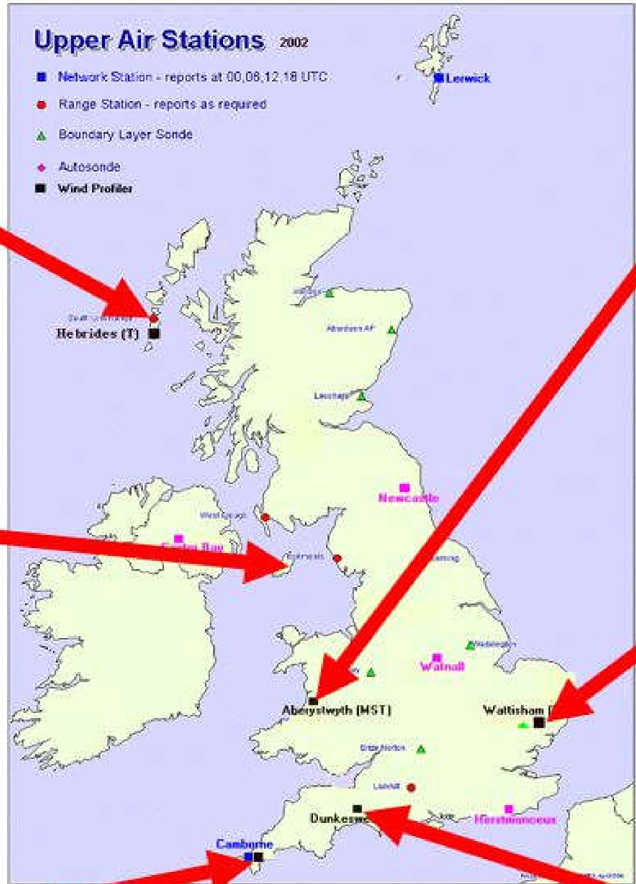
(*End 2020*)

Aberystwth MST Wind Profiler
owned & operated by NERC

UK Operational Wind Profiler Network



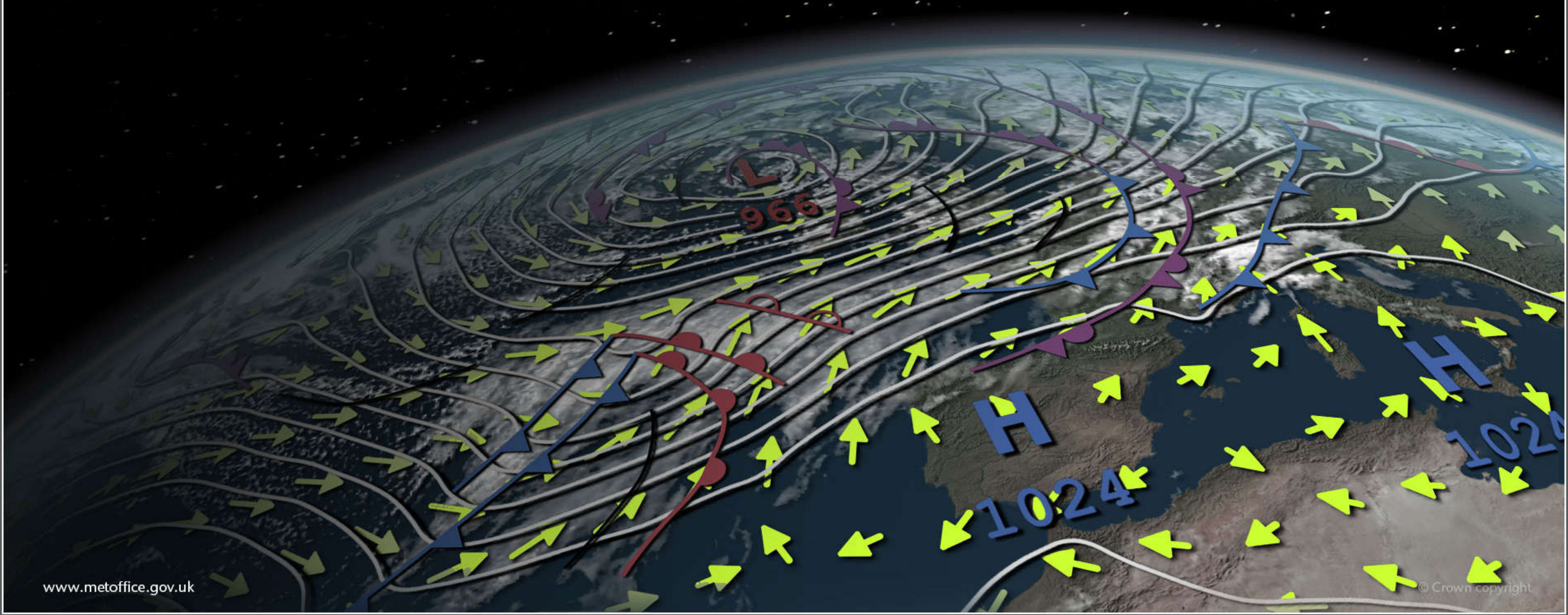
UK Operational Wind Profiler Network



Aberystwth MST Wind Profiler
owned & operated by NERC

Closures from 1st Oct

Further ahead
(operational in Summer 2019)

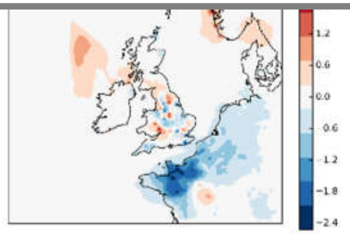


Soil Moisture DA for the UKV

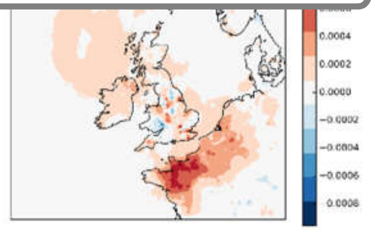
Met Office

Observations

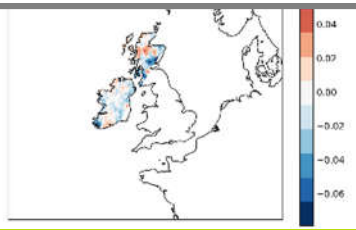
1.5m Temp (Gridded)



1.5m Spec Hum (Gridded)



ASCAT Soil Moisture



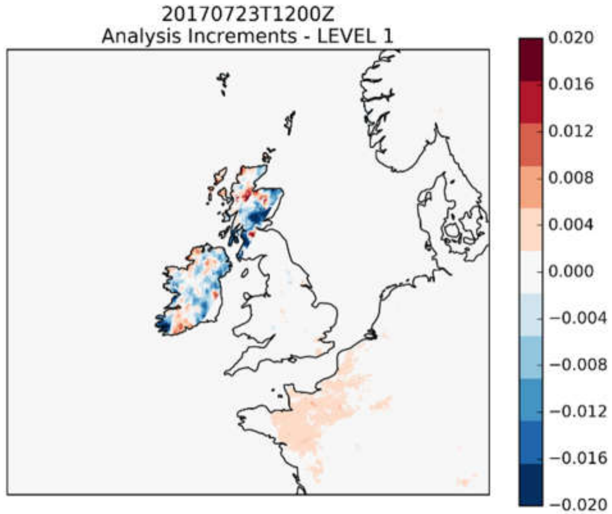
Simplified Extended Kalman Filter

$$x_i^b = x_i^b + K_i\left(y_i^o - H_i(x^b)\right)$$

$$\mathrm{K}_i = \mathrm{BH}^T\left(\mathrm{H}^T\mathrm{BH} + \mathrm{R}\right)^{-1}$$

- Currently interpolate global soil moisture daily, with freewheeling in UKV for 24 hours
- New system applies same EKF method used in global model at each hourly UKV analysis
- Obs interpolated to model grid
- B and R diagonal and isotropic, using realistic values of model and obs errors
- H(x) taken from model background
- Kalman Gain H estimated by finite differences, running offline Jules model with perturbations.

Soil moisture analysis increments

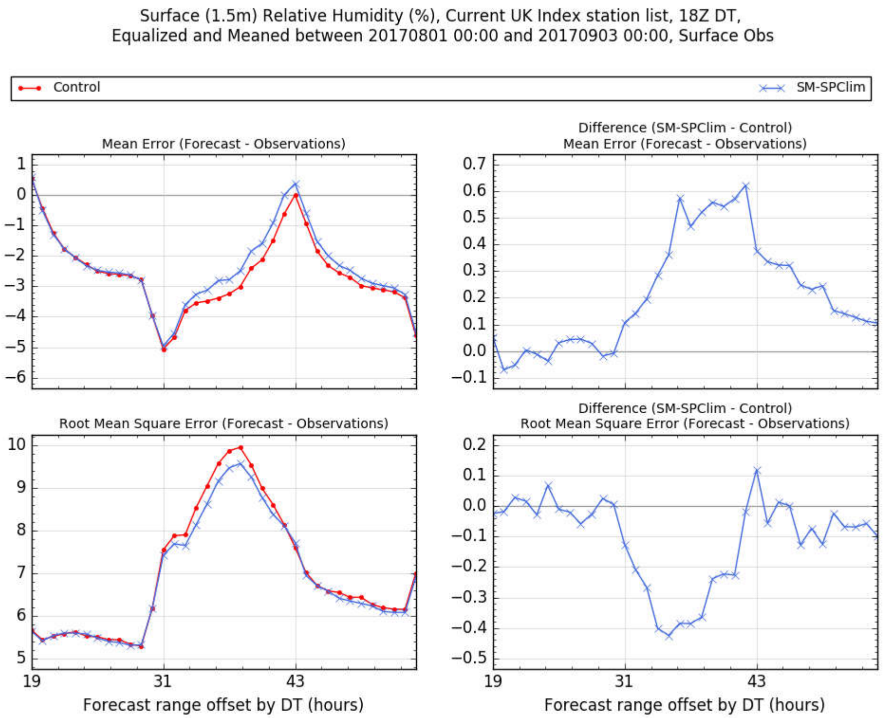


Breo Gomez, Cristina Charlton-Perez

Met Office

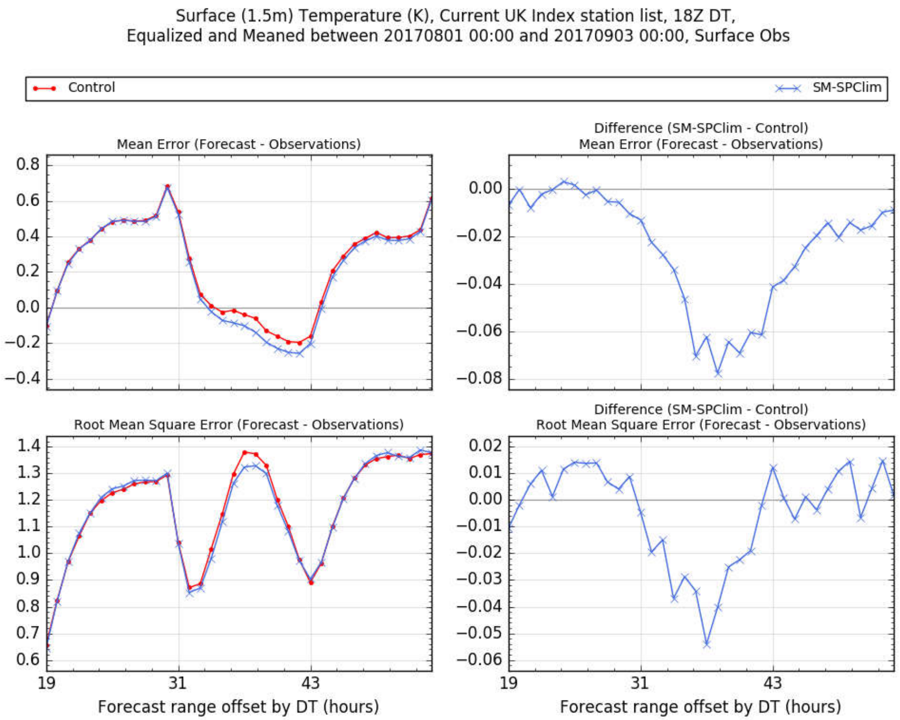
Soil Moisture DA (Aug 2017 trial)

1.5m Relative Humidity



Improvement in the BIAS and RMSE, particularly in early afternoon

1.5m Temperature



Cooler BIAS, but still shows substantial improvement of RMSE in early afternoon

Breo Gomez, Cristina Charlton-Perez

Future Plans

- Radar Reflectivity
- Snow analysis
- Sonde descent data
- Hybrid 4D-Var in UKV (*exploit improved ensemble*)
  - *In meantime, NMC method for 90 level covariances*

Questions?

Extras

FSOI in the UKV

- ❑ Technique established in global model, but new for UKV
  - ➢ measuring impact on 3-hour forecast
  - ➢ error metric is basket of SYNOP reports of T2m, RH2m, V10m, Vis2m
- ❑ Initial sample of 7 weeks data (combined Summer/Winter)
- ❑ Large run to run variability – but observations beneficial overall…….

Helen Buttery

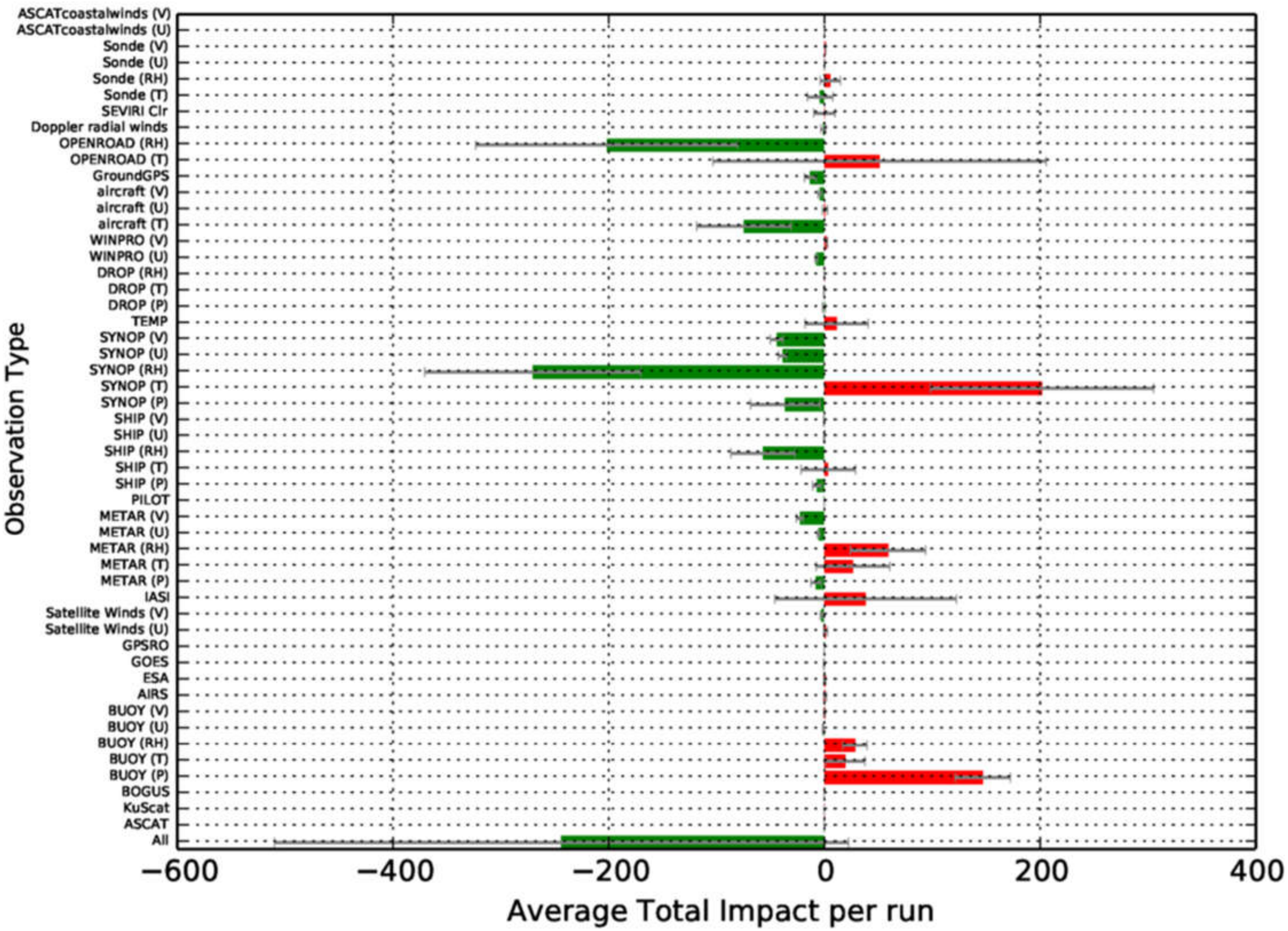
Met Office

Average Total FSOI Impact by Obs Type

Negative=beneficial
Positive=detrimental

Roadside RH2m and SYNOP RH2m provide largest beneficial impact

Detriments to investigate……..



Helen Buttery

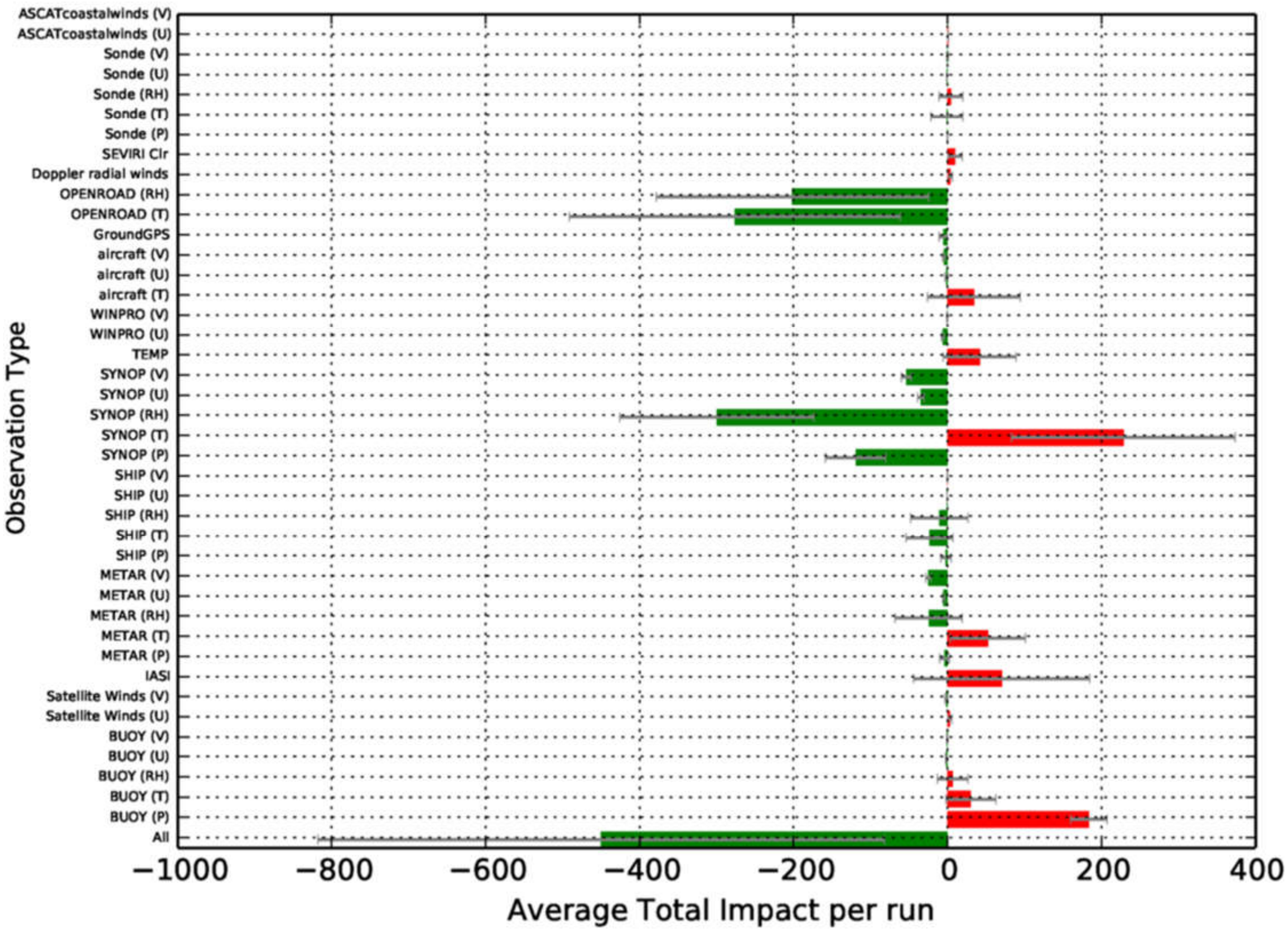
Met Office

Average Total FSOI Impact by Obs Type - *NEW COV*

Negative=beneficial
Positive=detrimental

Total benefit higher

Roadside T2m now beneficial, but SYNOP T2m still gives detriment……..



Helen Buttery

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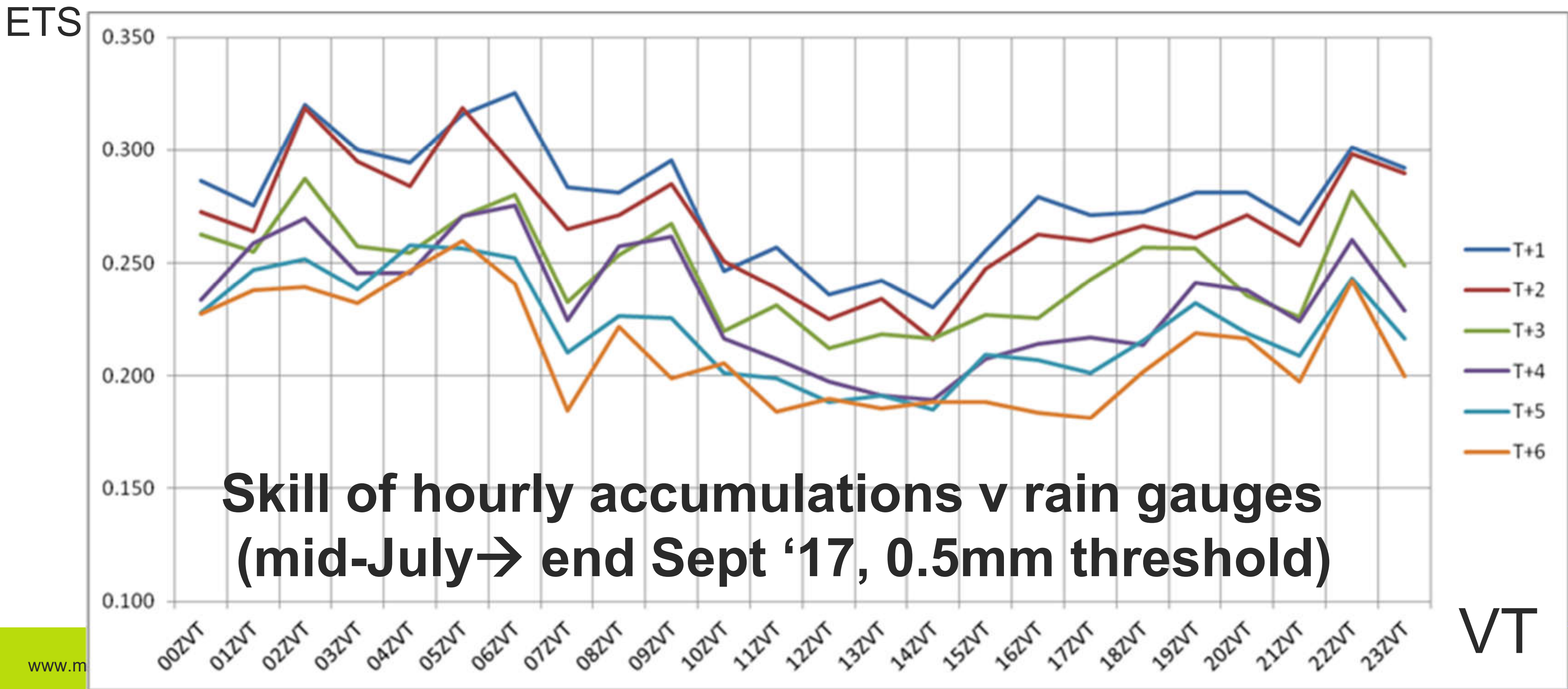
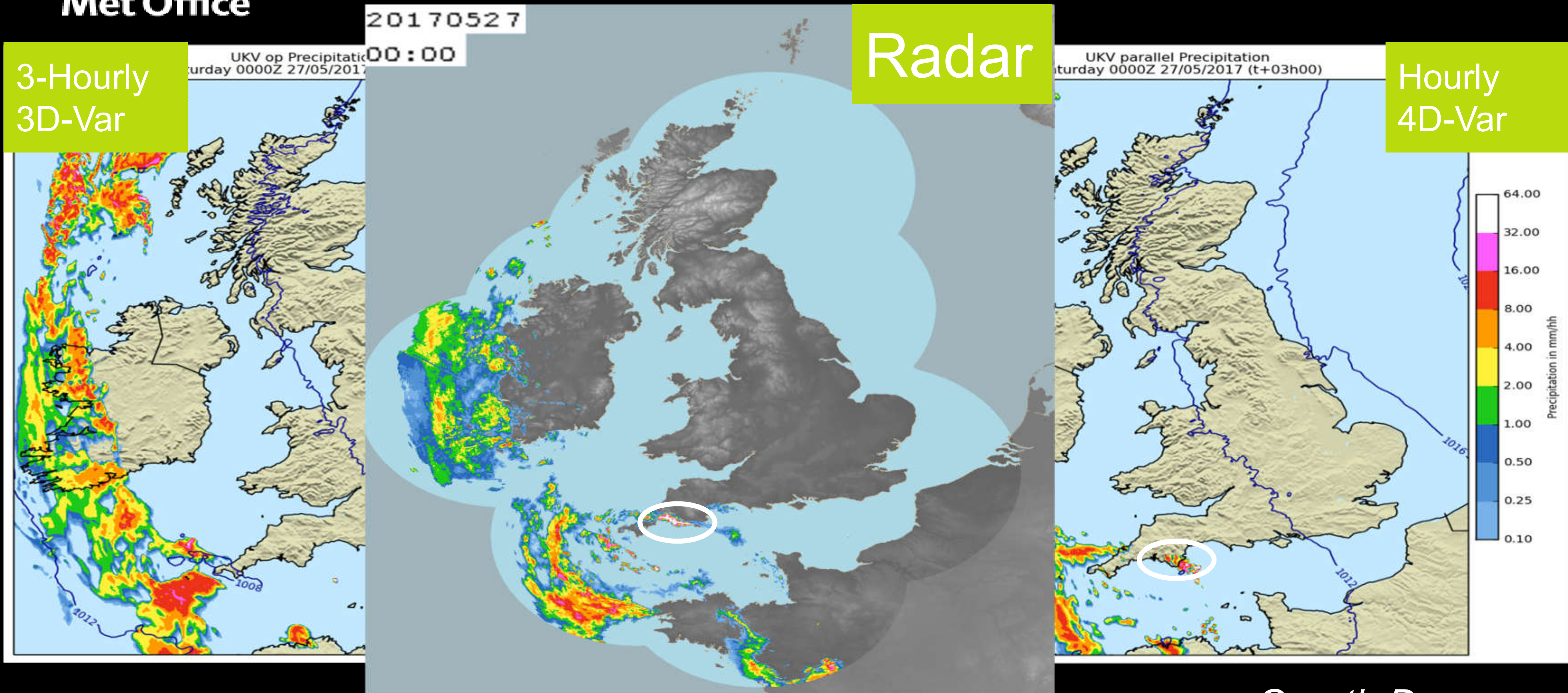
Gareth Dow

Value of hourly operational forecasts



Skill of hourly accumulations v rain gauges (mid-July→ end Sept ‘17, 0.5mm threshold)

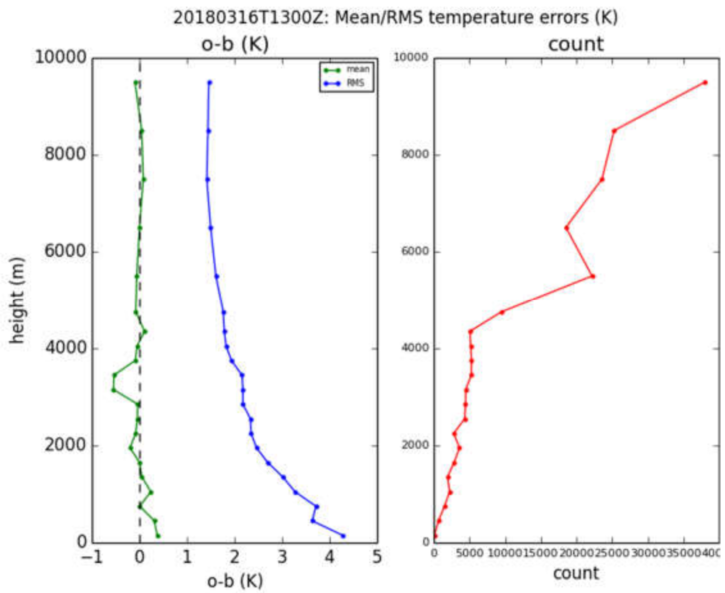
Plymouth Storm 00UTC May 27th T+3



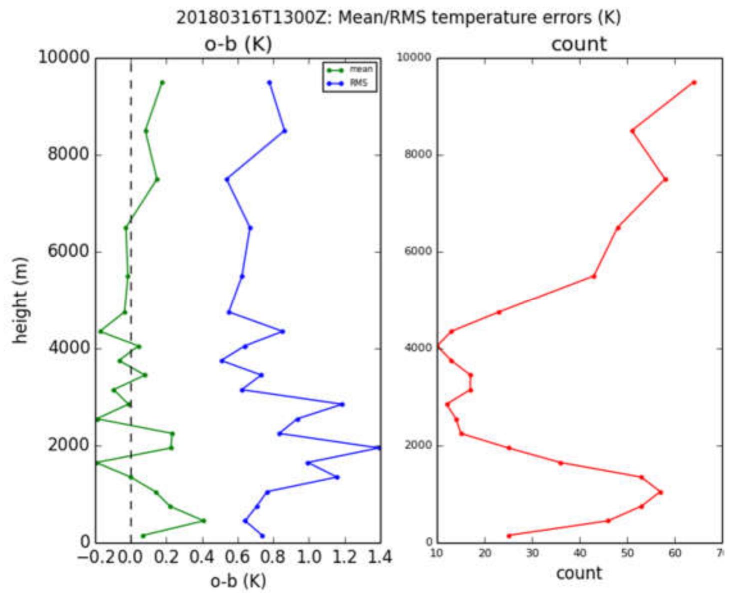
Gareth Dow

Routine monitoring of Mode-S data against operational UKV since July 2014 (Adam Maycock)

O-B RMS wind errors in Mode-S are similar to those in AMDARS at 2-3 m/s, but Mode-S temperature errors (~2.5 degrees) are much larger than AMDARS (~0.5-1.0 degrees).



Obs count, mean/RMS errors of O-B in Mode-S temperature 13Z cycle 13/03/18



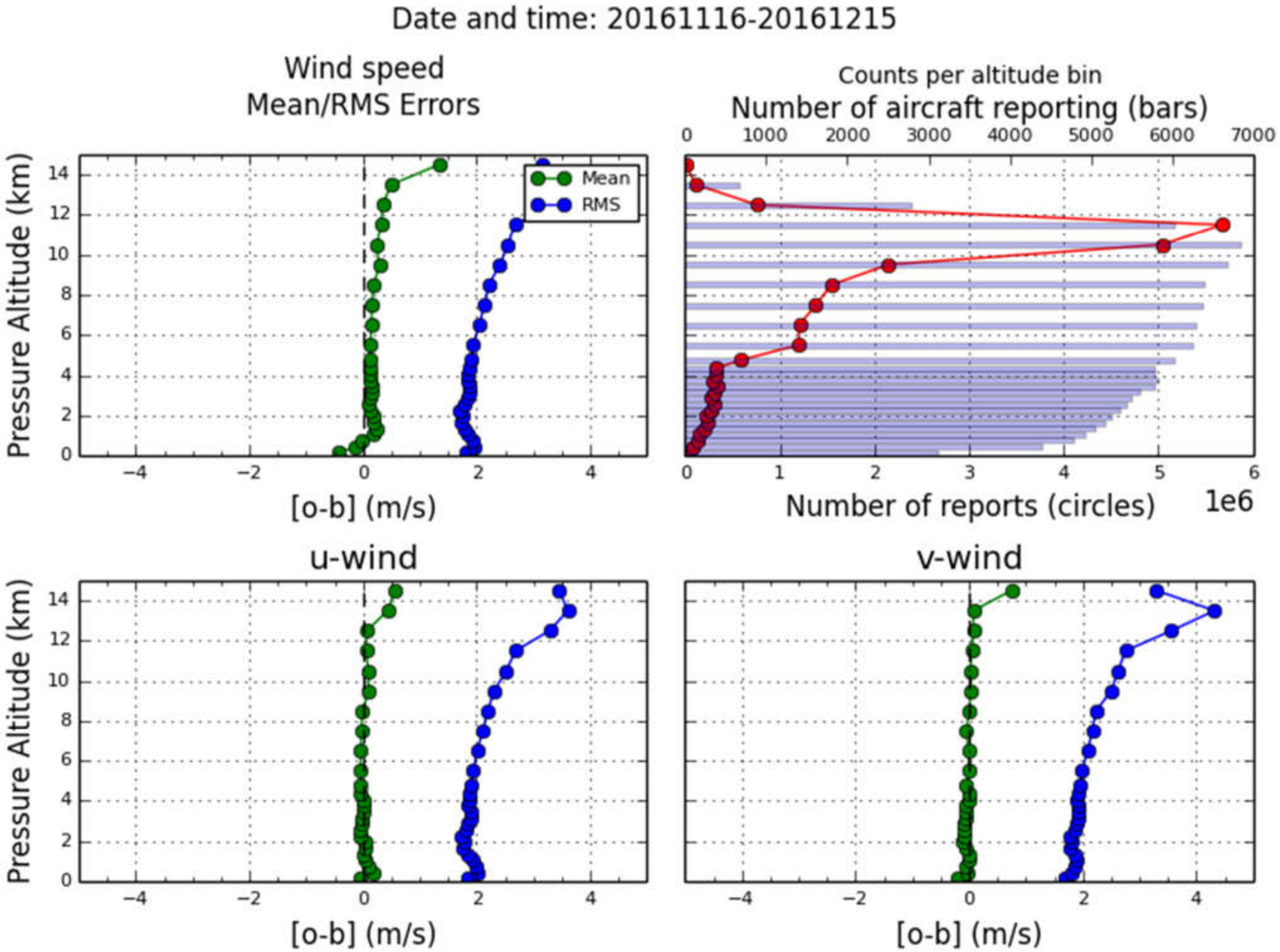
Obs count, mean/RMS errors of O-B in AMDAR temperature 13Z cycle 13/03/18

Assimilating Mode-S winds into hourly cycling 4D-Var UKV

- Experiment periods
  - Summer 2016: 01/07/2016 – 30/07/2016 (30 days)
  - Winter 2016: 16/11/2016 – 15/12/2016 (30 days)
- Experiments
  - Control: All existing routine types of observations with all AMDAR/AIREP but no Mode-S
  - Half AMDAR/AIREP: All existing routine types of observations with thinning of 80km x 50hPa x 120mins on AMDAR/AIREPS (winds, temperature and relative humidity) No Mode-S.
  - Mode-S T15: Half AMDAR/AIREP + Mode-S winds with 15mins thinning (winds only)
  - Mode-S T10: Half AMDAR/AIREP + Mode-S winds with 10mins thinning (winds only)

O-B Mode-S winds stats in T10W 16/11/16 – 15/12/16

RMS errors ~ 2 m/s at lower levels, increasing to ~ 3 m/s at 12km



O-B AMDAR winds stats in T10W) 16/11/16 – 15/12/16

RMS errors ~ 2-2.5 m/s at lower levels, increasing to ~ 3 m/s at 12km