# Met Office UKV 4D-Var, present and future plans

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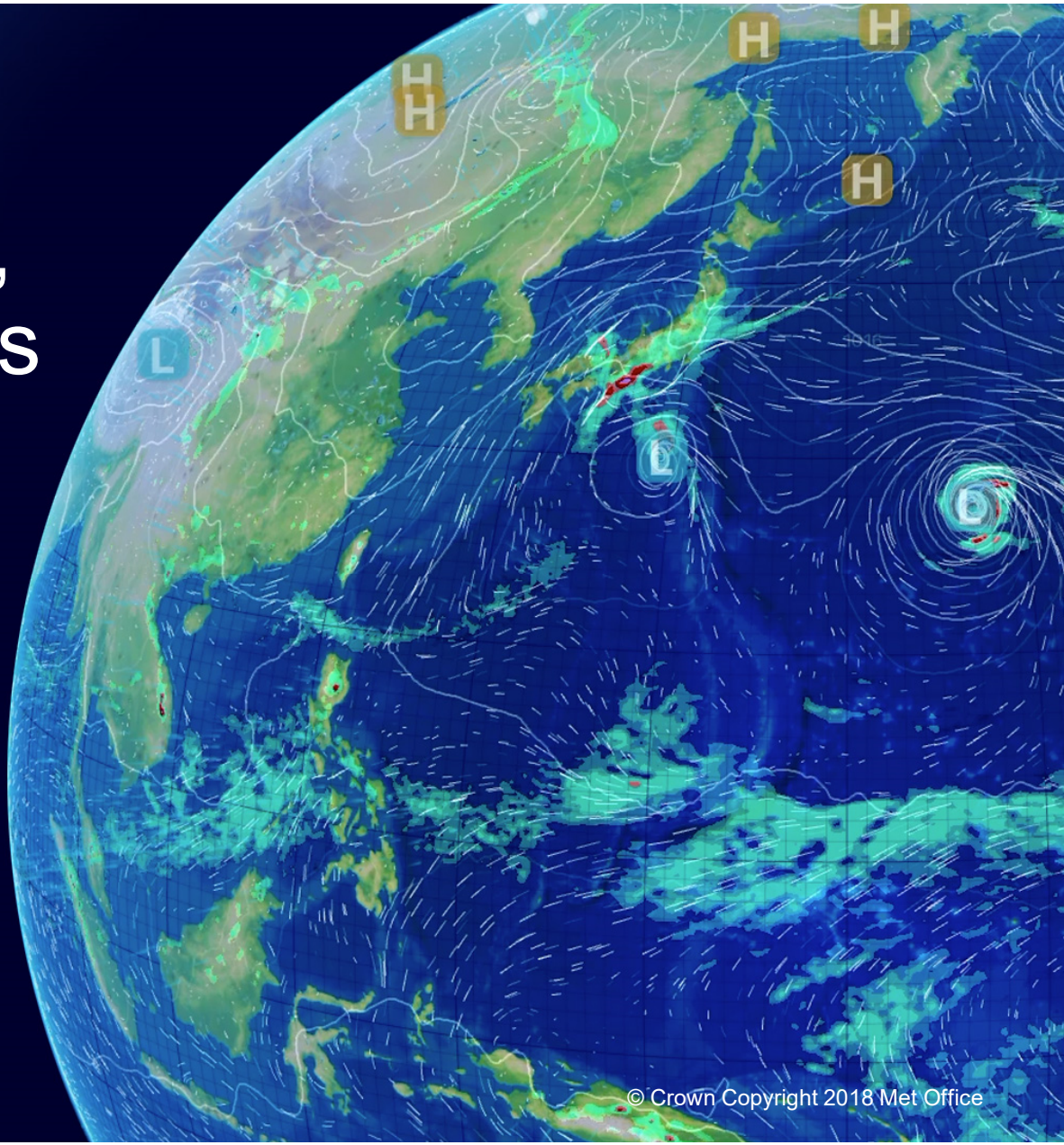
EWGLAM





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Met Office

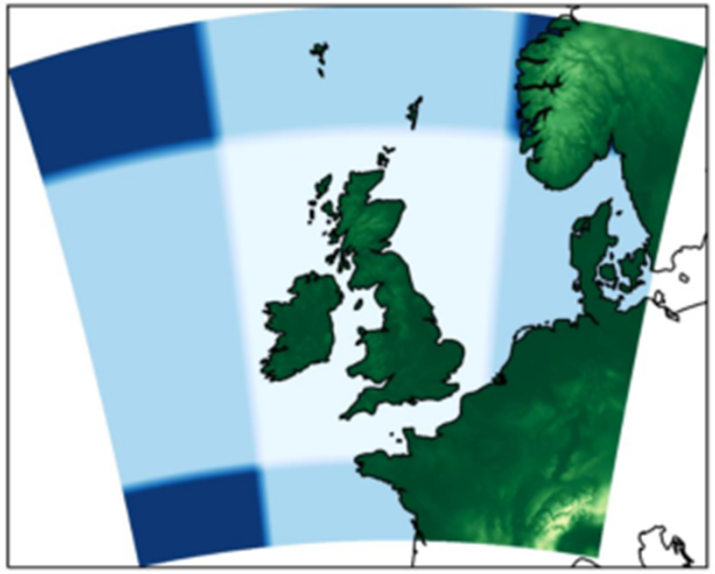
- The UKV 4D-Var configuration.
- Observations used in hourly cycling.
- Some recent results.

Development

- New vertical levels.
- Moisture incrementing operator.
- Hybrid 4D-Var.

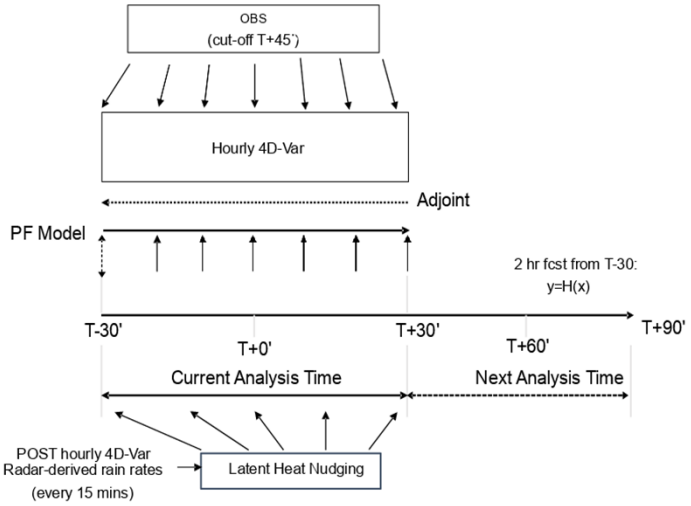
# Hourly UKV-4DVar configuration

UKV Domain



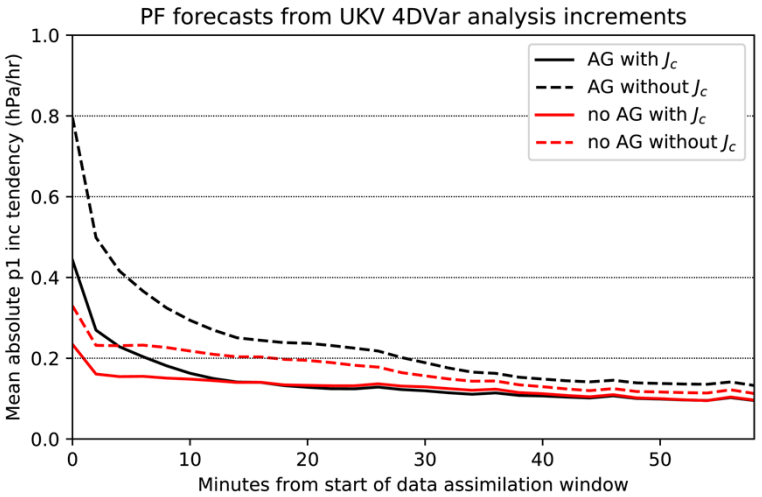
- Hourly 4D-Var assimilation method.
- Linear Perturbation Forecast (PF) model and DA, 4.5 km resolution (constant on the whole domain).
- UM model resolution in UK region 1.5km. Resolution 1.5x4 km along the edges and 4x4 km at the corners.
- Global boundary conditions 10km resolution.
- LBC from 00, 06, 12, 18 UTC from global model
  - Ages of LBC runs lies in range T-3 : T-8.
- Observation cut-off 45 mins, 80 mins only for 11UTC and 23 UTC (to catch radiosonde data).
- VarBC applied to satellite radiances.
- Operational forecast in range T+12:T+120.

# Hourly UKV-4DVar cycle



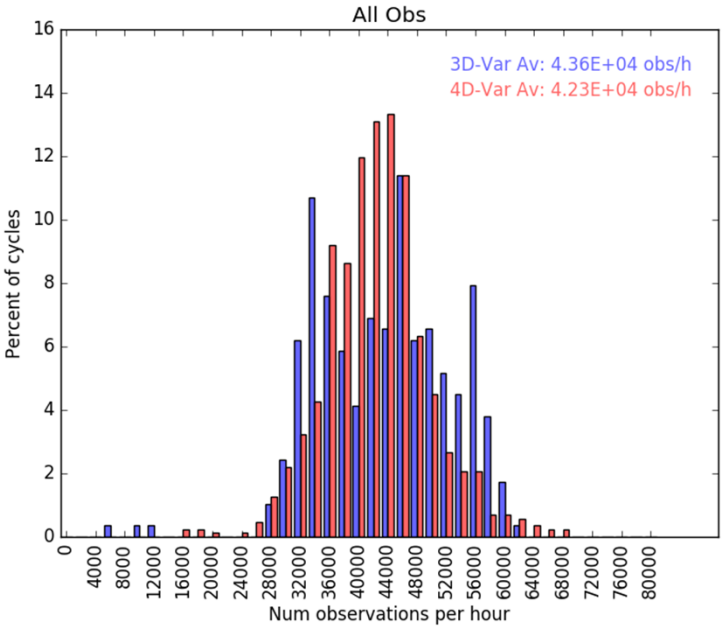

- Assimilation window centered around T+0, nominal analysis time. Between T-30mins to T+30mins.
- Model integration from T-30mins onward, providing the background for the next cycle.
- Model fields converted into simulated OBS.
- Incremental 4D-Var data assimilation.
- 7 LS states (1 every 10 minutes).
- Single outer loop.
- PF model not the exact tangent-linear model but a simplified model for finite perturbations.
- Latent heat nudging applied after 4D-Var.

# Vertical adaptive grid and digital Filtering




- The vertical adaptive grid adjusts the grid points to enhance the vertical resolution where the gradient of potential temperature is larger (e.g. inversions, cloud top).
- The vertical adjustment is used in the CVT, however it creates some unbalanced increments.
- The UKV 4D-var uses a digital filter constraint term (Jc) to the data assimilation cost function.
- Penalise high-frequency oscillations, such as inertia-gravity waves.
- Energy norm only related to the elastic potential energy.

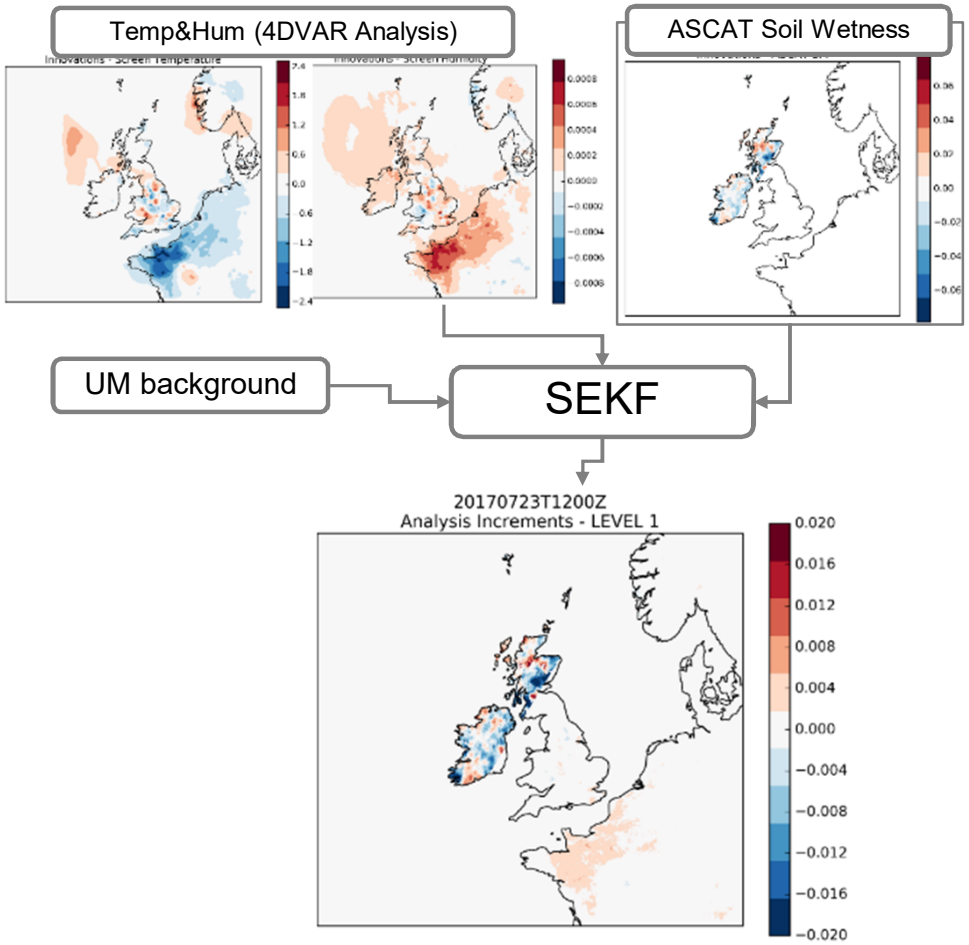
# Observation used




- Wide range of instruments:
  - Satellites
  - Surface observation
  - In-situ upper air
  - Ground based remote sensing
  - Recently, Mode-S aircraft data wind only. Strong impact in the first hours of forecast. Especially upper level wind.
- Observations available at a wide range of times are optimal in an hourly 4D-Var environment.
- Before hourly 4D-Var the Met-Office operational system was a 3H3D-Var, whith a larger cut-off time. This has the capacity of used more observations.
- Some types of observations can be assimilated more frequently than in a 3D-Var environment, where observations close in time to the nominal analysis time tend to give best performances.

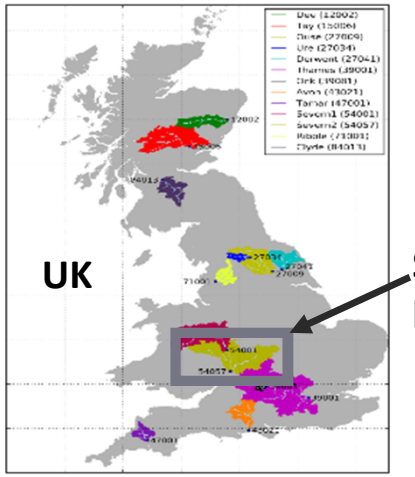
# New: UKV Soil Moisture analysis

- *Replaces the daily reconfiguration of the Global SMC analysis*
- Follows the same methodology used in the Global NWP suite.
  - Algorithm: **S**implified **E**xtended **K**alman **F**ilter
  - Observations:
    - Screen temperature and humidity from 4DVAR atm. analysis
    - ASCAT satellite soil wetness (scatterometer)
- Hourly cycling
- Provides soil moisture analysis
- Small impact in atmosphere
  - improves screen humidity summer
- Large impact on hydrology, with very promising results. (Next slide)

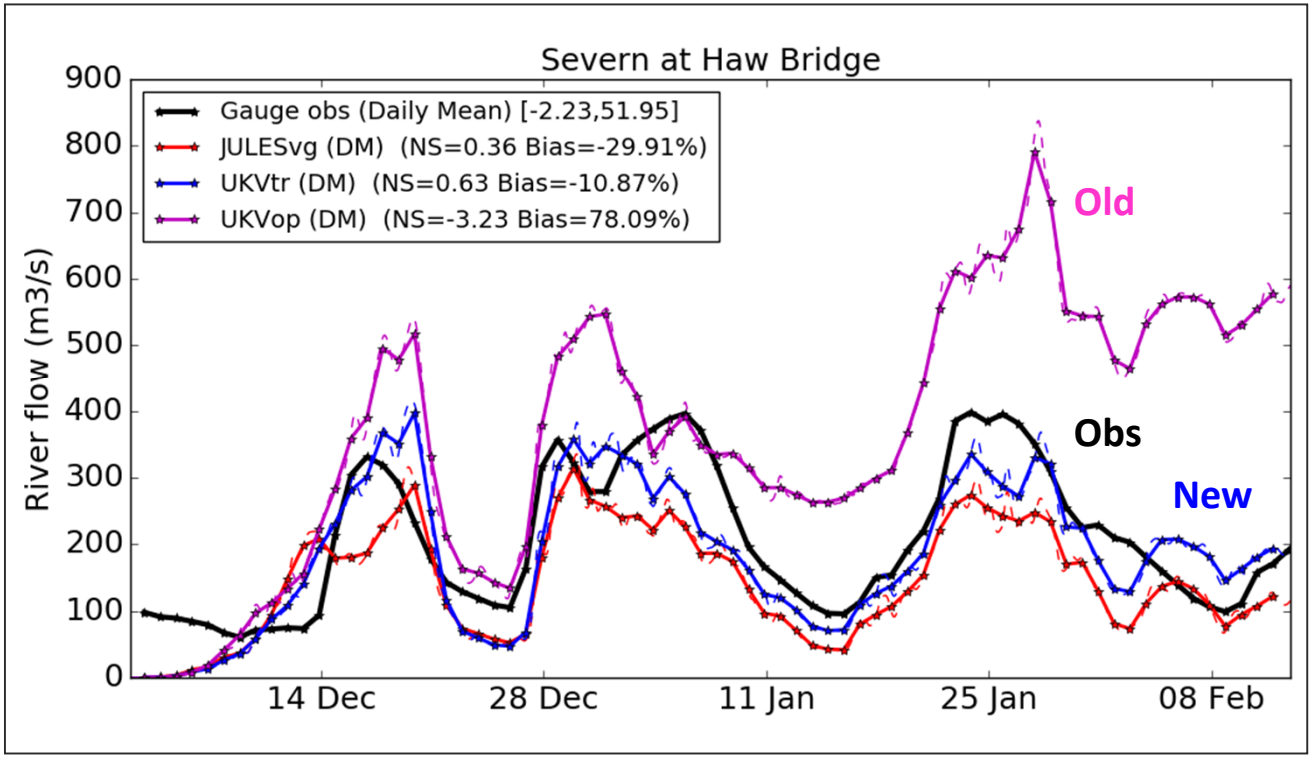



Courtesy of Breo Gomez

# New: UKV Soil Moisture analysis



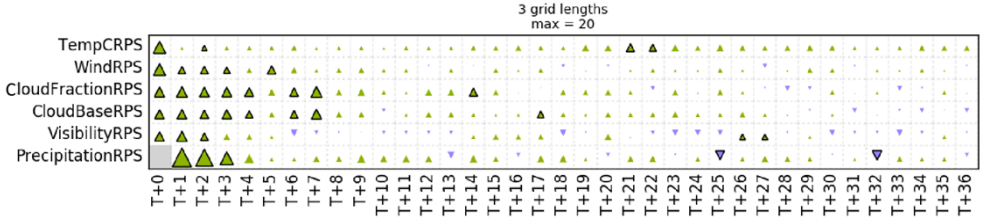

- Improved run-off leads to improved river flow
- Simulated river flows are much more realistic for the trial with EKF
- Opens the possibility to produce operational river flows from UKV



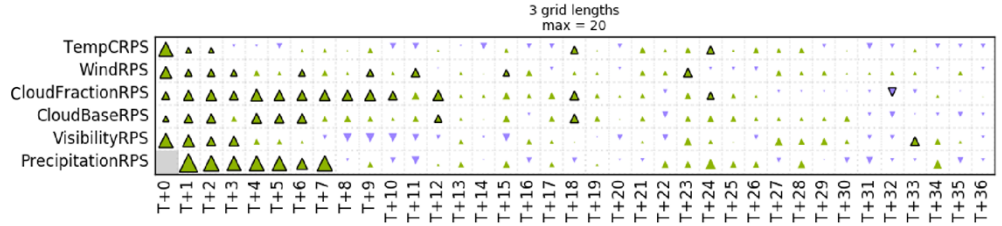

Special thanks to Huw Lewis

# Some results

WINTER



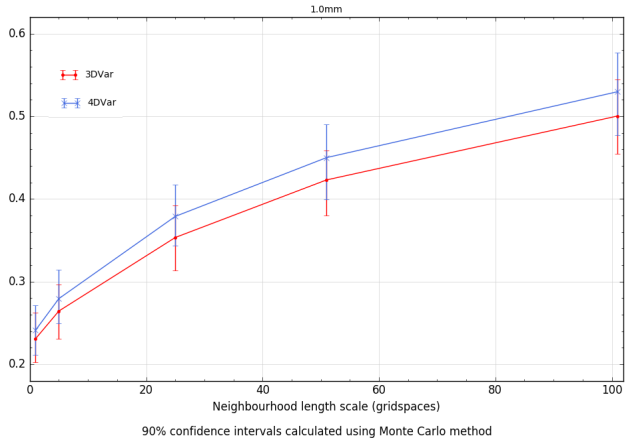

SUMMER

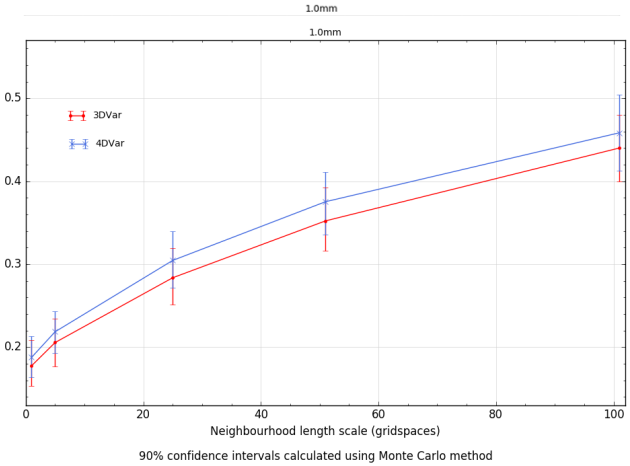



- Comparison 4D-Var vs 3D-Var:
  - Both hourly cycling.
  - Clean comparison for impact of the system only.
  - One winter and one summer month.
- Use of Hinton diagram, a visual comparison of skills. Bold triangles if statistically significant.
- Improvement for every field, from T+3 for screen temperature to T+7 for cloud fraction.
- Benefits probably due to the flow dependency of 4D-Var.

# Some results

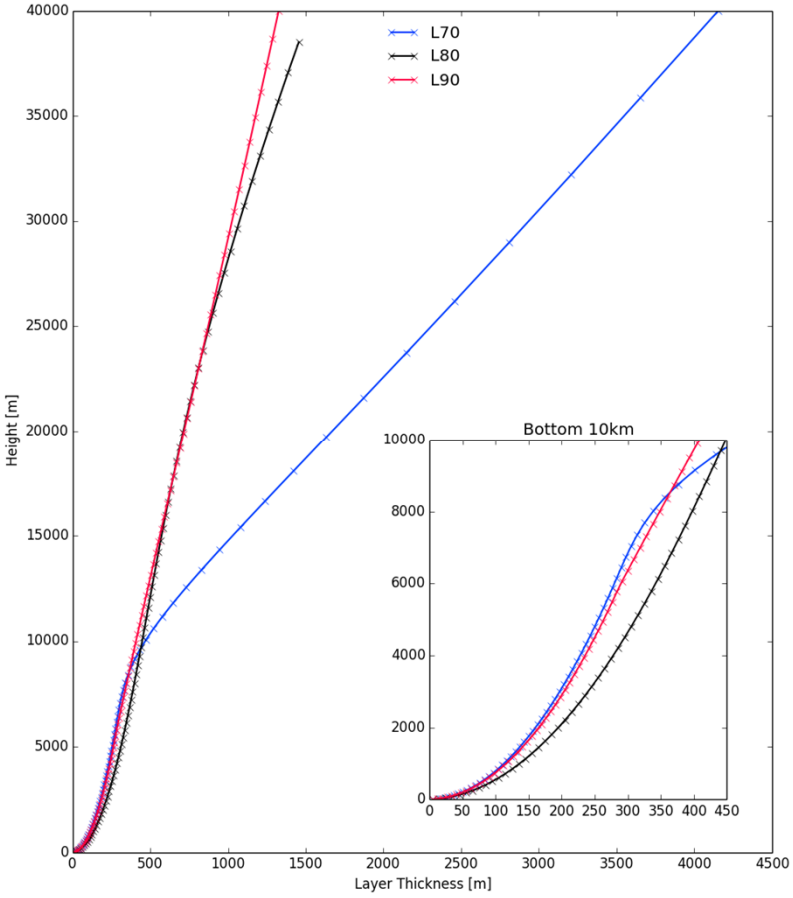
SUMMER
WINTER




- FSS hourly accumulated precipitation. Threshold 1mm at T+3 hours and T+6 hours.
- For all neighborhoods 4D-Var is superior, but differences not statistically significant.
- Winter and summer have similar results.
- Differences slightly higher at T+3.

# 90 Vertical levels




Courtesy of Anke Finnenkoetter

- UKV from 70 levels (Blue) to 90 levels (red) in 2020/2021.
- Upper troposphere higher resolution for 90 levels.
- Lower troposphere slightly higher resolution for 70 levels.
- From previous results (Anke Finnenkoetter):
  - Positive impact in cloud forecast.
  - Some positive impact in screen surface temperature over sea. Difficult to verify because of sparse observation.
- We are computing:
  - Static covariances for 90 levels starting from global downscaling and from UKV analysis.
  - 1D-Var Bmatrix for different satellite instruments for OPS (used for quality control). Partly in the OBS operator in VAR.

# Humidity increments

- The actual 4D-Var algorithm uses only increments in water vapour, not in liquid and frozen cloud.
- Moisture Incrementing Operator (Migliorini et al., 2018):
  1. Used in the obs operator and in PF model.
  2. Operates in cloudy regions.
  3. Uses a theoretical definition of the relationship between the humidity variables.
  4. Uses a training from MOGREPS-UK (for UKV).
  5. Combines point 3 and 4 with an offline linear regression to compute new increments in all humidity variables.
- Early results:
  - MIO significantly enhanced the precipitation skills.

# MIO – AG relationship

- MIO and AG are not theoretically consistent:
- The AG changes the vertical gradient of the control variables variance, so that the variances are not isotropic anymore.
- AG changes vertical derivative of the ageostrophic pressure and its standard deviation (i.e. the vertical derivative of standard deviation of temperature). This changes the T vertical profile.
- The moisture control variable changes are not related to pressure, Thus its standard deviation vertical derivative will not change.
- A different temperature can lead to saturation and increasing q. MIO gives rise to different qcl and qcf.
- We had cases of high spurious precipitation during the first 20 minutes of the assimilation window.
- AG has a strong impact (e.g. sea fog) in standard 4D-Var, as static covariances are homogeneous and isotropic. Hybrid 4D-Var can lead to retirement of AG.

# Hybrid 4D-Var

- Operational in the global model.
- Introduces the "error of the day" in the covariances.
- Different approaches for the ensemble:
  - MOGREPS-G.
  - MOGREPS-UK.
  - Use of forecast differences as "pseudo-ensemble" (method suggested from Chen et al., 2018).
- Even using ensembles with large number of members. We need localisation to reduce sampling noise.
- Want the horizontal localisation to be approximately homogeneous across the domain, despite the presence of the lateral boundaries.
- First tests suggest to apply localisation in PF space.

# Conclusions

- Hourly 4D-Var improved significantly the forecast of LAM, at least in the first 6-9 hours.
- The skill enhancement is due to use of hourly cycle but also to the change from 3D-Var to 4D-Var.
- Potentially, we can still largely improve the system:
  - Mode-S assimilation of temperature
  - EKF for soil moisture analysis
  - Hybrid
  - 90 levels
  - MIO
- A paper about our system is under review from QJRMS:
  "Hourly 4D-Var in the Met Office UKV operational forecast model"