UKV model physics developments

Presented by Mike Bush

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- New ice Particle Size Distribution (PSD)
- Modified Ice Fallspeed
- Revised cloud fraction diagnostic
- New rain PSD.
- Prognostic graupel.
- Stable Boundary Layer.

Microphysics schemes and the UM

- The UM microphysics scheme is a single moment bulk scheme that just has particle mass density as a prognostic
- Microphysics schemes can be divided into 'bulk' schemes and 'bin' schemes
- Computational limitations currently prohibit the use of a 'bin' scheme in many models such as the UM.
- Bin schemes explicitly calculate the evolution of the particle size distribution (PSD) for rain, ice and other species
- Bulk schemes on the other hand assume some functional form for the PSD. More complicated double moment schemes also include number concentration as a prognostic.
- The PSD is needed to get all of the microphysical transfer rates written in terms of the thing you know
- d(qcf)/dt = Process 1 (function (qcf)) + … + Process N (function (qcf))

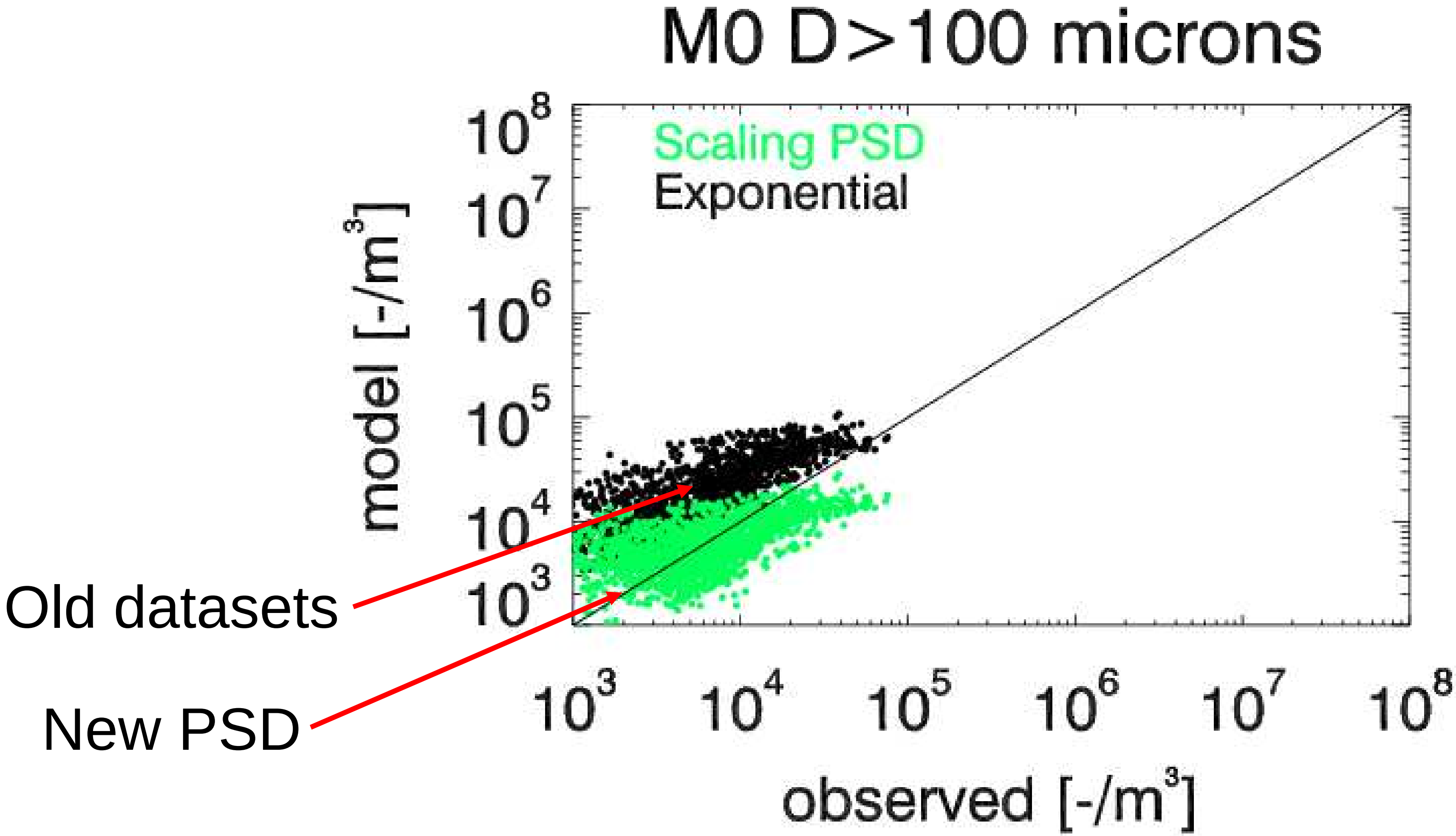
Microphysical processes represented by the UM

- Fall of ice and rain under gravity
- Primary nucleation of ice particles by heterogeneous and homogeneous nucleation
- Deposition and sublimation of ice
- Aggregation: The collection of ice particles by other ice particles
- Riming: Ice particles collecting cloud droplets, which freeze on impact
- Capture of raindrops by falling ice particles, which increases the ice content
- Melting of ice particles
- Evaporation of rain
- Accretion: The collection of cloud droplets by raindrops
- Autoconversion: The production of rain and drizzle by converting cloud water into rain

Generic Ice PSD

- The idea of a generic ice particle size distribution (PSD) is to calculate the microphysical transfer rates between ice and other water species.
- The version used up to 17/01/12 (PS27) was based on Houze et al. (1979).
- Old datasets suffer from ice shattering artefacts leading to an overestimate in the number of small particles.

Zeroth moment, M0 – Number density



New Ice PSD introduced into operations

Met Office

- A new ice PSD was introduced operationally on 17/01/12 (PS28).
- It is based on Field et al, (2007).
Snow size Distribution Parametrization for Midlatitude and Tropical Ice Clouds. **JAS, 64, 12, pp 4346-4365**
- Based on better quality observational data and a bigger sample taken not only in the midlatitudes but also the tropics
- It was discovered during the final testing that the cirrus was much less prevalent than SEVIRI observations indicated.
- An incorrect setting had led to a fallspeed relationship that is approximately a factor of 2 too high when compared to observations
- A decision was made to continue with the implementation and fix this bug at PS29 in January 2012.

Ice particle fallspeed

• Mitchell, D (1996). Use of Mass- and Area- Dimensional Power Laws for Determining Precipitation Particle Terminal Velocities. **JAS Vol. 53, No.12, 1710-1723.**

• The fallspeed estimate requires 3 inputs:

1) Mass - Diameter (dimension) relationship
2) Area - size relationship.
3) Reynolds - Best relationship

• Fallspeed =

$$v_t = a\nu\left(\frac{2\alpha g}{\rho_a \nu^2 \gamma}\right)^b D^{b(\beta+2-\sigma)-1}$$

a = Best-Reynolds tunable parameter
b = Best-Reynolds tunable parameter
alpha = Mass - diameter relationship tunable parameter
beta = Mass - diameter relationship tunable parameter
gamma = Area - size relationship parameter (currently hardwired)
sigma = Area - size relationship parameter (currently hardwired
eta = dynamic viscosity
g = gravitational acceleration
rho_a = air density
D = maximum dimension of the particle

Coefficients and exponents to mass- and area-dimensional power laws for ice particle types

Particle type	Mass α	Mass β	Area γ	Area σ	References
Hexagonal plates					Mitchell and Arnott (1994), [c]Mitchell et al. (1996), Auer and Veal (1970)
$15\ \mu m \leqslant D \leqslant 100\ \mu m$	0.00739	2.45	0.24	1.85	
$100\ \mu m < D \leqslant 3000\ \mu m$	0.00739	2.45	0.65	2.00	
Hexagonal Columns					Mitchell and Arnott (1994), Auer and Veal (1970), [c]Mitchell et al. (1996), Heymsfield and Knollenburg (1972)
$30\ \mu m < D \leqslant 100\ \mu m$	0.1677	2.91	0.684	2.00	
$100\ \mu m < D \leqslant 300\ \mu m$	0.00166	1.91	0.0696	1.50	
$D > 300\ \mu m$	0.000907	1.74	0.0512	1.414	
Rimed long columns					Mitchell et al. (1990), Auer and Veal (1970)
$200\ \mu m \leqslant D \leqslant 2400\ \mu m$	0.00145	1.8	0.0512	1.414	
Crystal with sector-like branches (P1b),					Pruppacher and Klett (1978), [c]Mitchell et al. (1996)
$10\ \mu m \leqslant D \leqslant 40\ \mu m$	0.00614	2.42	0.24	1.85	
$40\ \mu m < D \leqslant 2000\ \mu m$	0.00142	2.02	0.55	1.97	
Broad-branched crystal (Plc),					Pruppacher and Klett (1978), [c]Mitchell et al. (1996)
$10\ \mu m \leqslant D \leqslant 100\ \mu m$	0.00583	2.42	0.24	1.85	
$100\ \mu m < D \leqslant 1000\ \mu m$	0.000516	1.80	0.21	1.76	
Stellar crystal with broad arms (P1d),					Pruppacher and Klett (1978), [c]Mitchell et al. (1996)
$10\ \mu m \leqslant D \leqslant 90\ \mu m$	0.00583	2.42	0.24	1.85	
$90\ \mu m < D \leqslant 1500\ \mu m$	0.000270	1.67	0.11	1.63	
Densely rimed dendrites (R2b),					Locatelli and Hobbs (1974)
$1800 \leqslant D \leqslant 4000\ \mu m$	0.0030	2.3	0.21[a]	1.76[a]	
Side planes (S1),					Mitchell et al. (1990), [a]Mitchell et al. (1996)
$300\ \mu m \leqslant D \leqslant 2500\ \mu m$	0.00419	2.3	0.2285[b]	1.88[b]	
Bullet rosettes, 5 branches at −42°C,					Mitchell (1994), [a]Mitchell et al. (1996)
$200\ \mu m \leqslant D \leqslant 1000\ \mu m$	0.00308	2.26	0.0869	1.57	
Aggregates of side planes,					Mitchell et al. (1990), [c]Mitchell et al. (1996)
$600\ \mu m \leqslant D \leqslant 4100\ \mu m$	0.0033	2.2	0.2285[b]	1.88[b]	
Aggregates of side planes, columns and bullets (S3),					Mitchell et al. (1990), [c]Mitchell et al. (1996)
$800\ \mu m \leqslant D \leqslant 4500\ \mu m$	0.0028	2.1	0.2285[b]	1.88[b]	
Assemblages of planar polycrystals in cirrus clouds,					[c]Mitchell et al. (1996)
$20\ \mu m \leqslant D \leqslant 450\ \mu m$	0.00739[c]	2.45[c]	0.2285	1.88	
Lump graupel (R4b),					Locatelli and Hobbs (1974), Heymsfield and Kajikawa (1987)
$500\ \mu m \leqslant D \leqslant 3000\ \mu m$	0.049	2.8	0.50[d]	2.0[d]	
Hail					Matson and Huggins (1980)
$0.5\ cm \leqslant D \leqslant 2.5\ cm$	0.466	3.0	0.625	2.0	

UM Agg

Reynolds (Re) - Best (X) relationship

Field et al. (2008)
JAS, Volume 65, pp 376-391

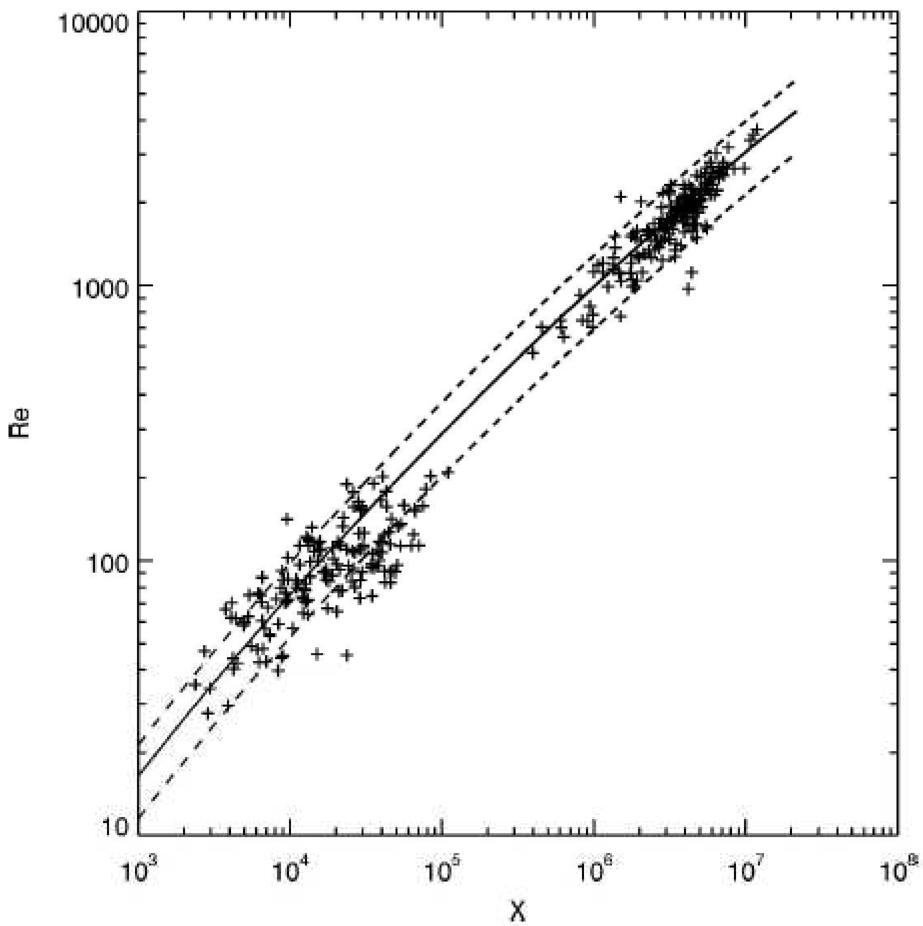


FIG. 5. The Reynolds number (Re)–Best number (X) relationship used to estimate particle fall speed (from Mitchell and Heymsfield 2005). The data points are for aggregates. The solid line is the relationship given in Mitchell and Heymsfield (2005). The dashed lines are perturbations of this relation by ±30% that were adopted for the sensitivity analysis.

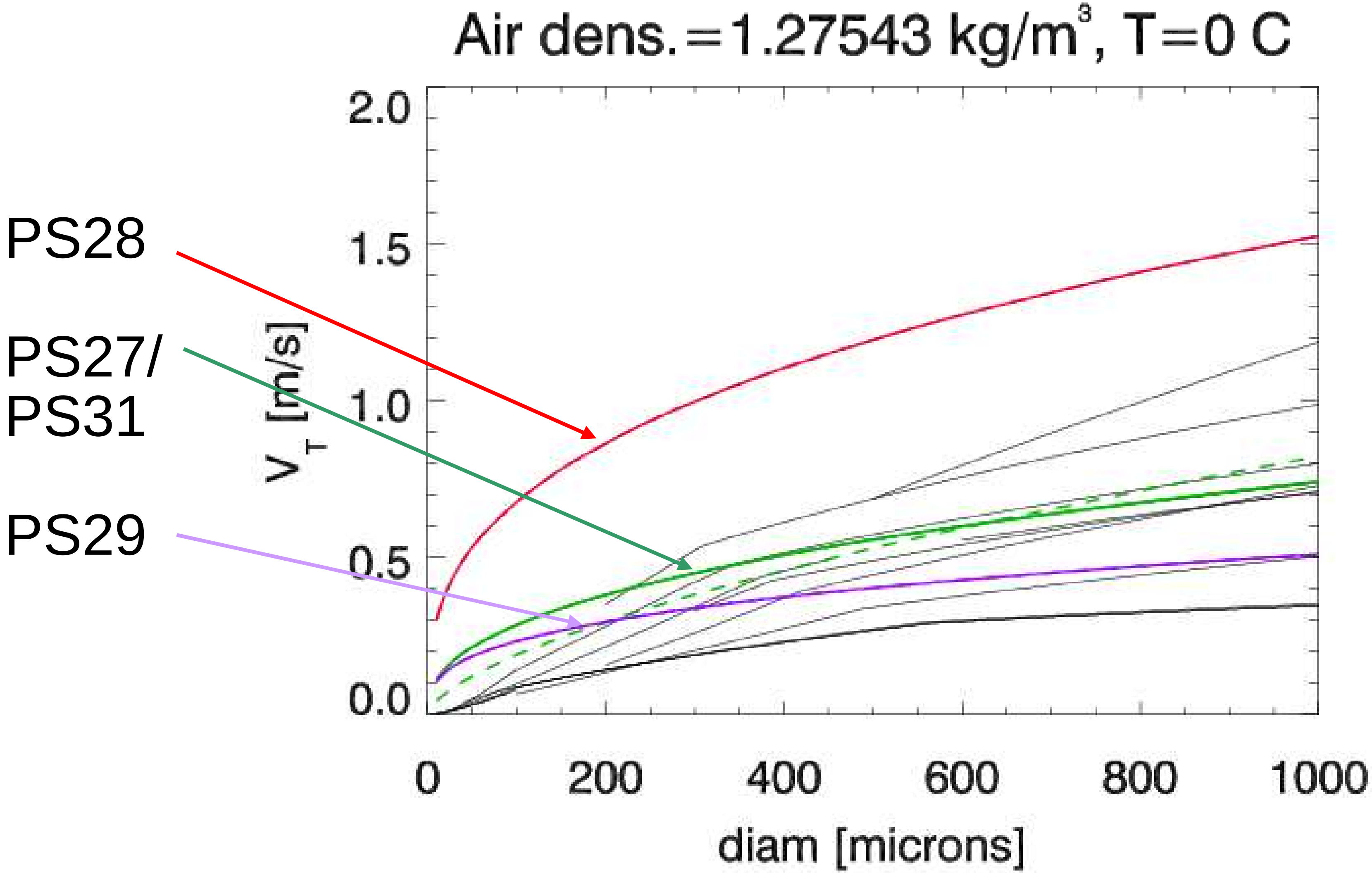
Reducing the ice fallspeed to boost cirrus…

- A change was tested for PS29 (March 2012) that reduced the ice fallspeed (more ice stays in the cirrus cloud)
- This was achieved by more than halving one of the Reynolds - Best parameters
- Unfortunately there were detrimental impacts on precipitation, so the change was not implemented operationally and further tests were carried out.
- So for PS31 (November 2012) both the mass – diameter parameters and the Reynolds – Best parameters were changed.
- The mass – diameter parameters were changed to agree with the latest observational data from the ‘Constrain’ campaign that involved the FAAM research aircraft.
- A paper on this has been accepted by QJ (Cotton & Field).

Met Office

Ice fallspeed – Diameter relation

Black lines are from Mitchell (1996)



Ice fallspeed – Diameter relation

Brandes et al. (2008)
Journal of Applied Meteorology and Climatology,
Volume 47, Issue 10 pp 2729-2736

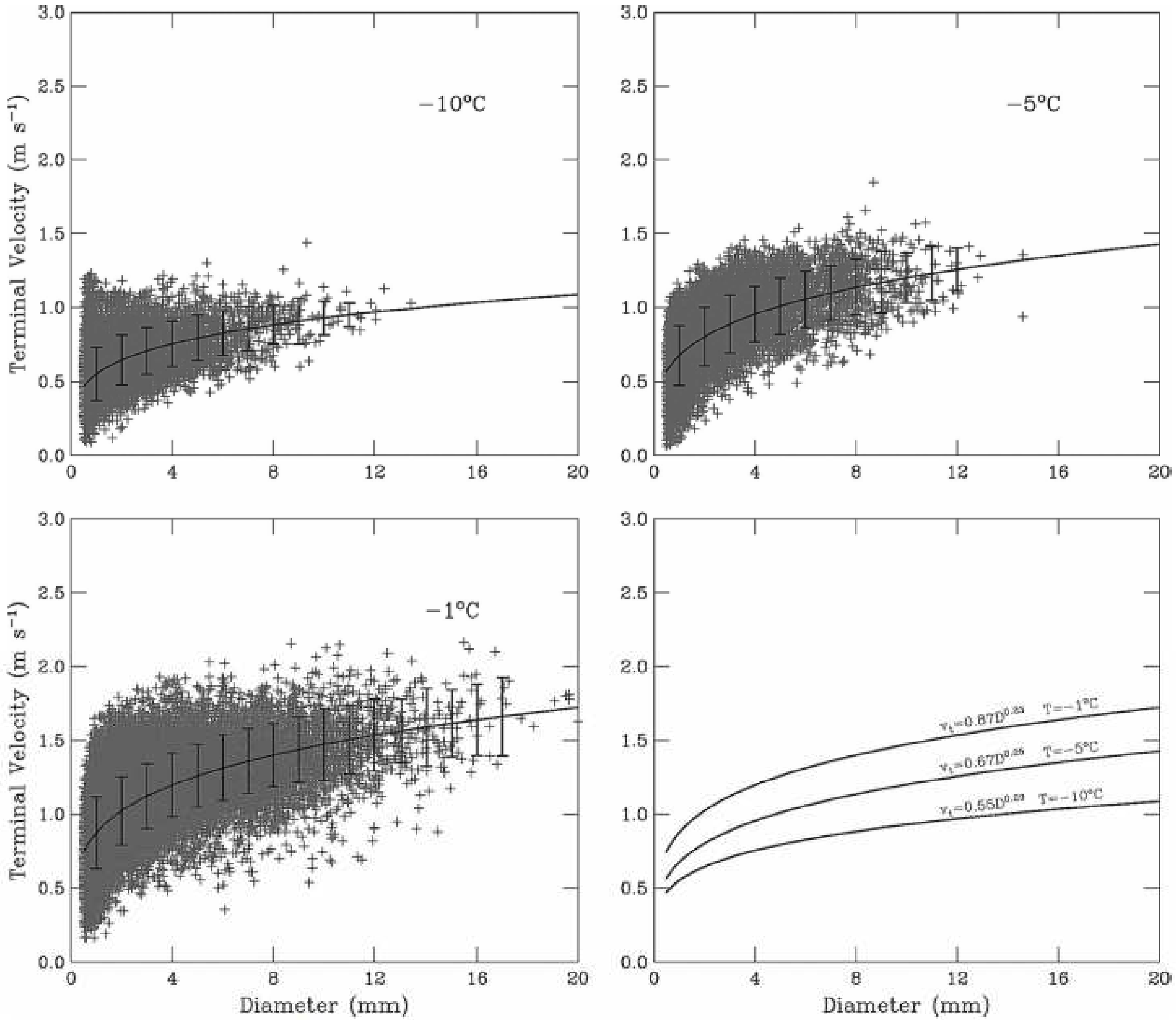
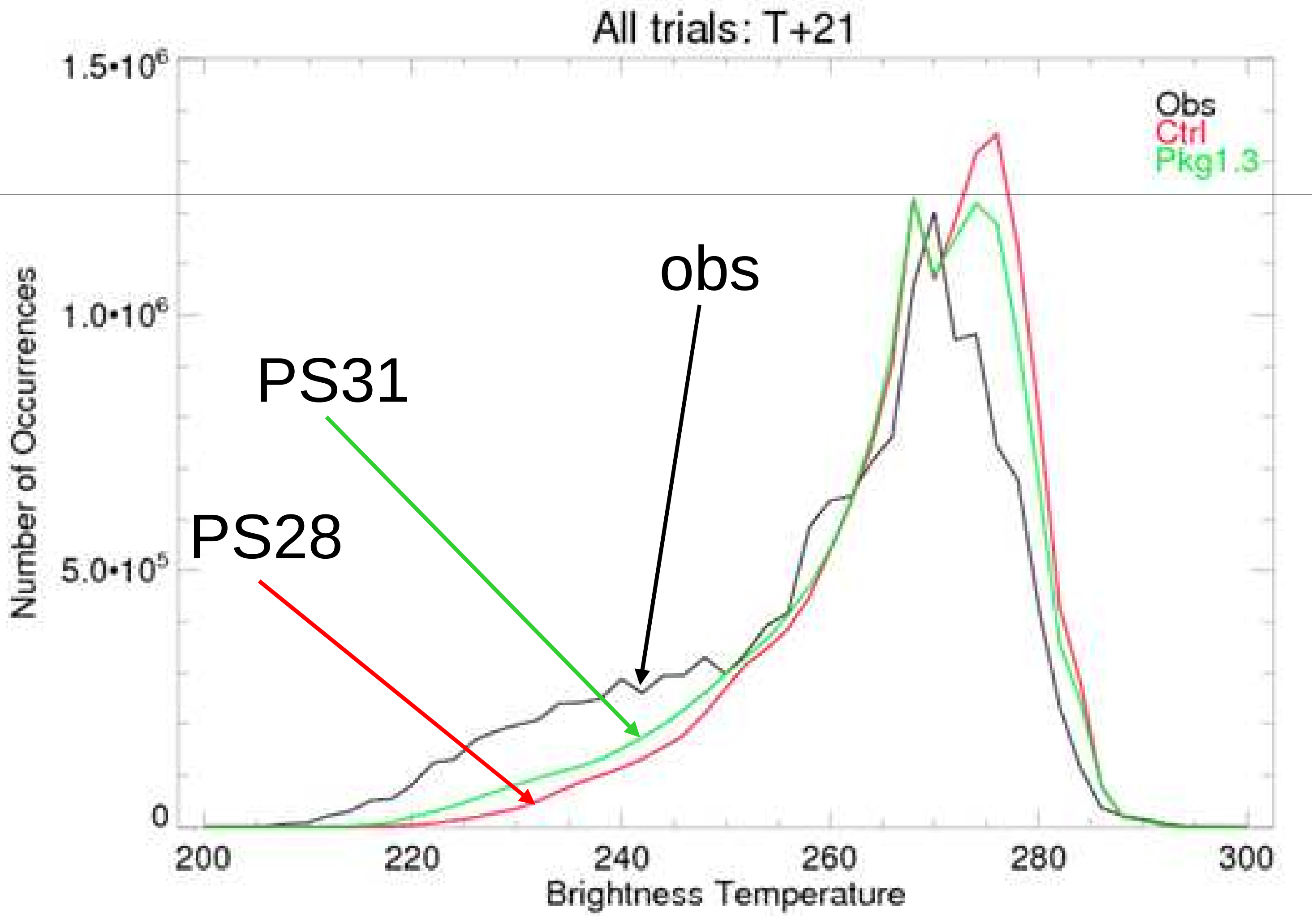


FIG. 3. Hydrometeor terminal velocities plotted vs equivalent-volume diameter for various temperatures. Fitted relations (2)–(4) are overlaid. Standard deviations are shown by vertical bars.

Reduced Ice Fallspeed: SEVIRI channel 9 reconstructions



Model cloud too low - not cold enough?

Courtesy: Mark Weeks

Reduced Ice Fallspeed: SEVIRI channel 9 reconstructions

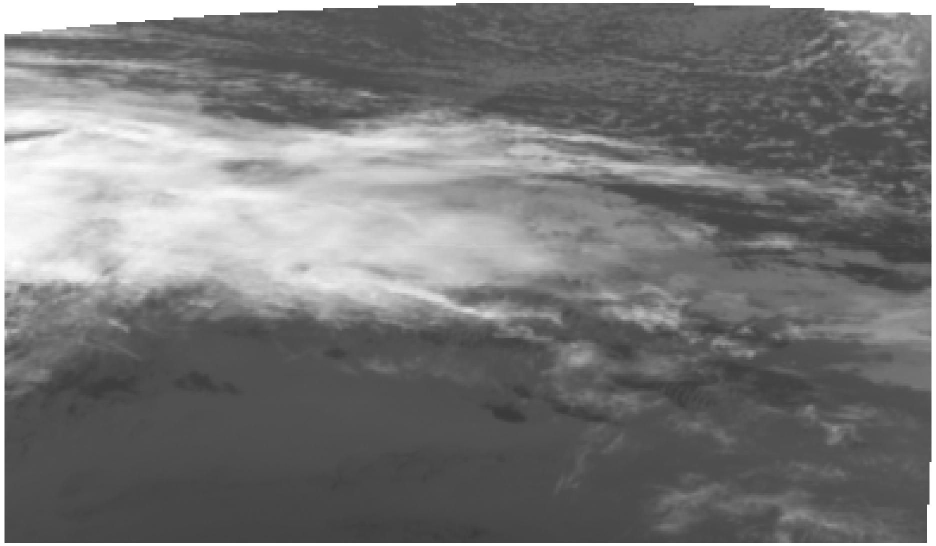


Figure 2a observations SEVIRI ch9

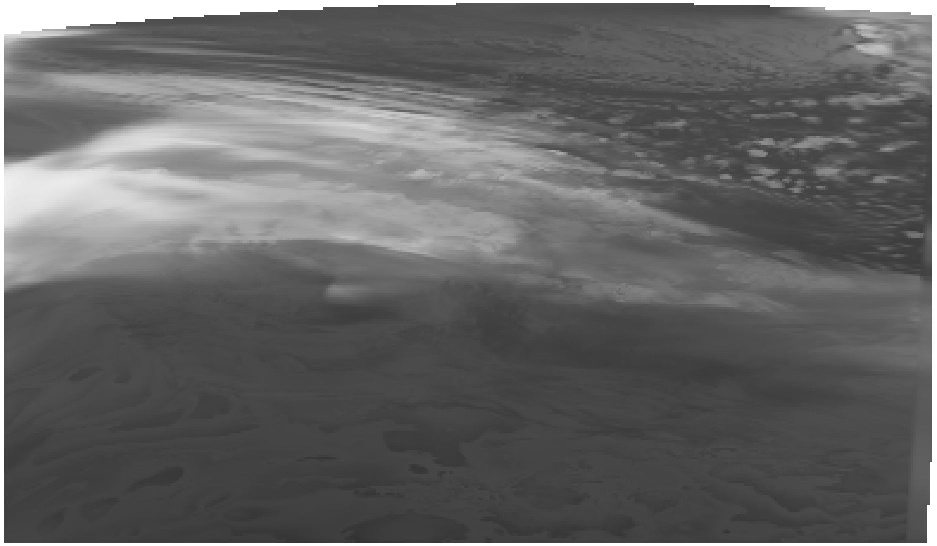


Figure 2c Current operational SEVIRI ch9 simulated

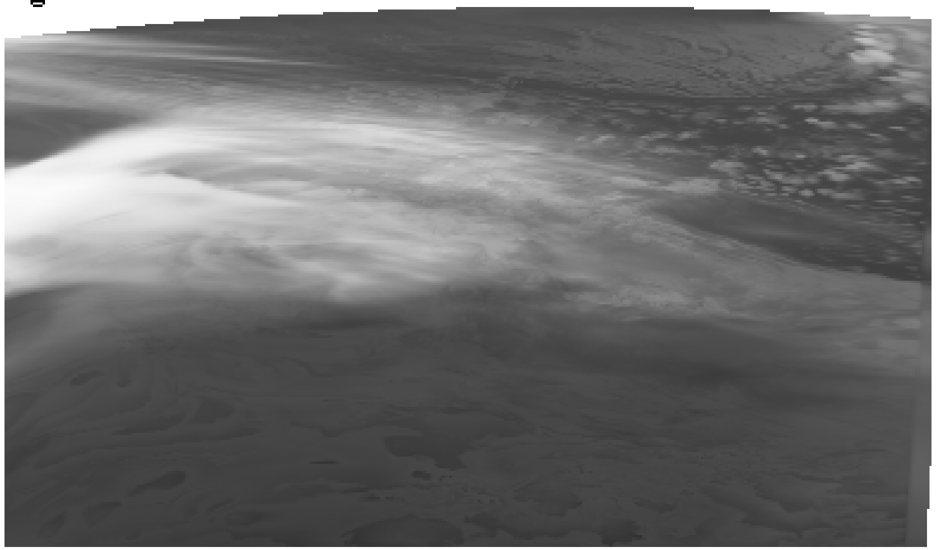


Figure 2b Pkg 1.3 corrected ice fallspeed SEVIRI ch9 simulated

obs

PS28

PS31

Courtesy: Mark Weeks

Reduced Ice Fallspeed: Impact on cirrus

Met Office

Lack of cirrus

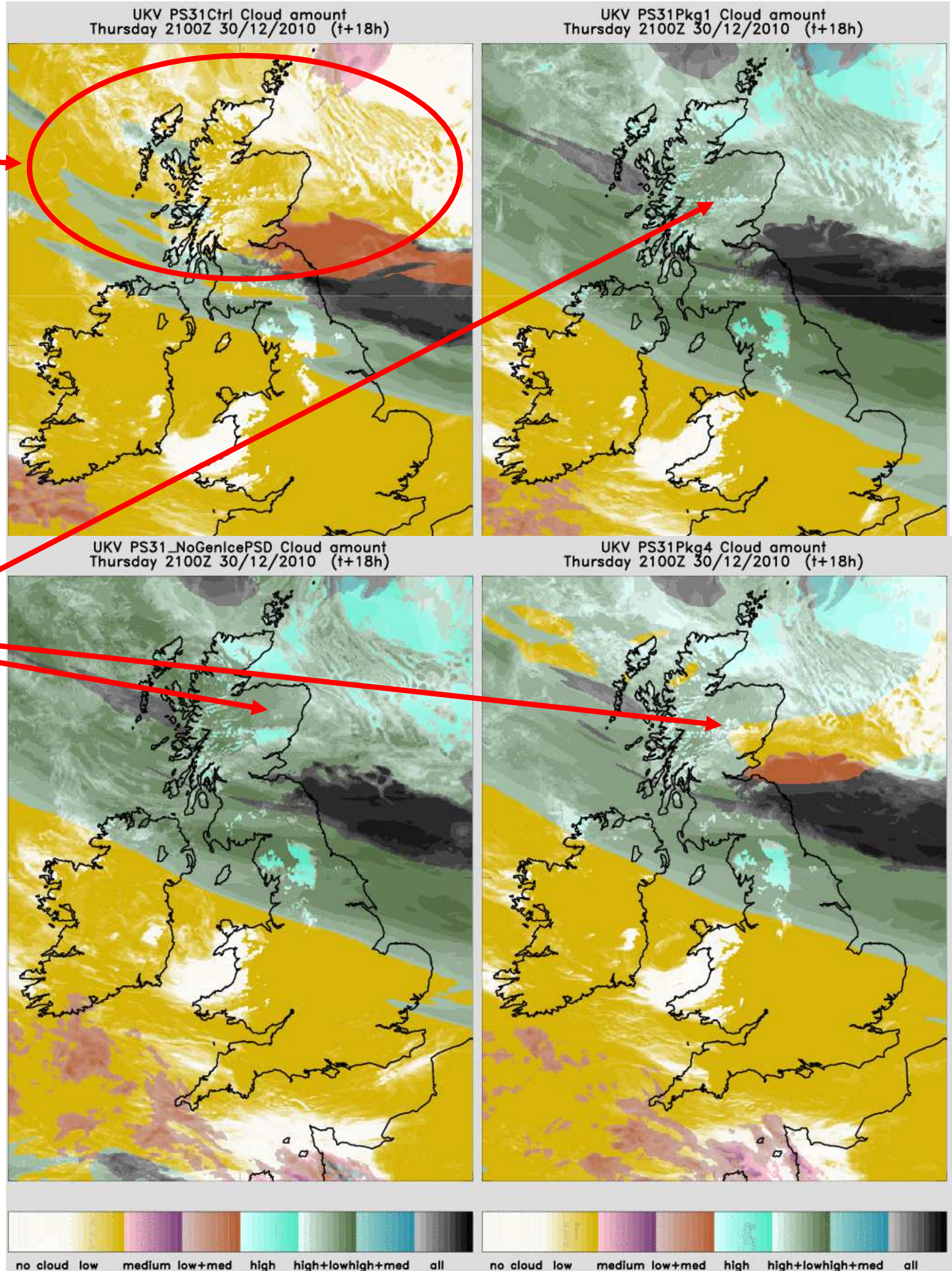
PS28

New ice PSD

Cirrus
(Shaded grey)

PS27

Old ice PSD



PS29

New ice PSD
Fallspeed to
low but cloud
ok

PS31

New ice PSD

Reduced Ice fallspeed: Impact on ppn

Met Office

PS28

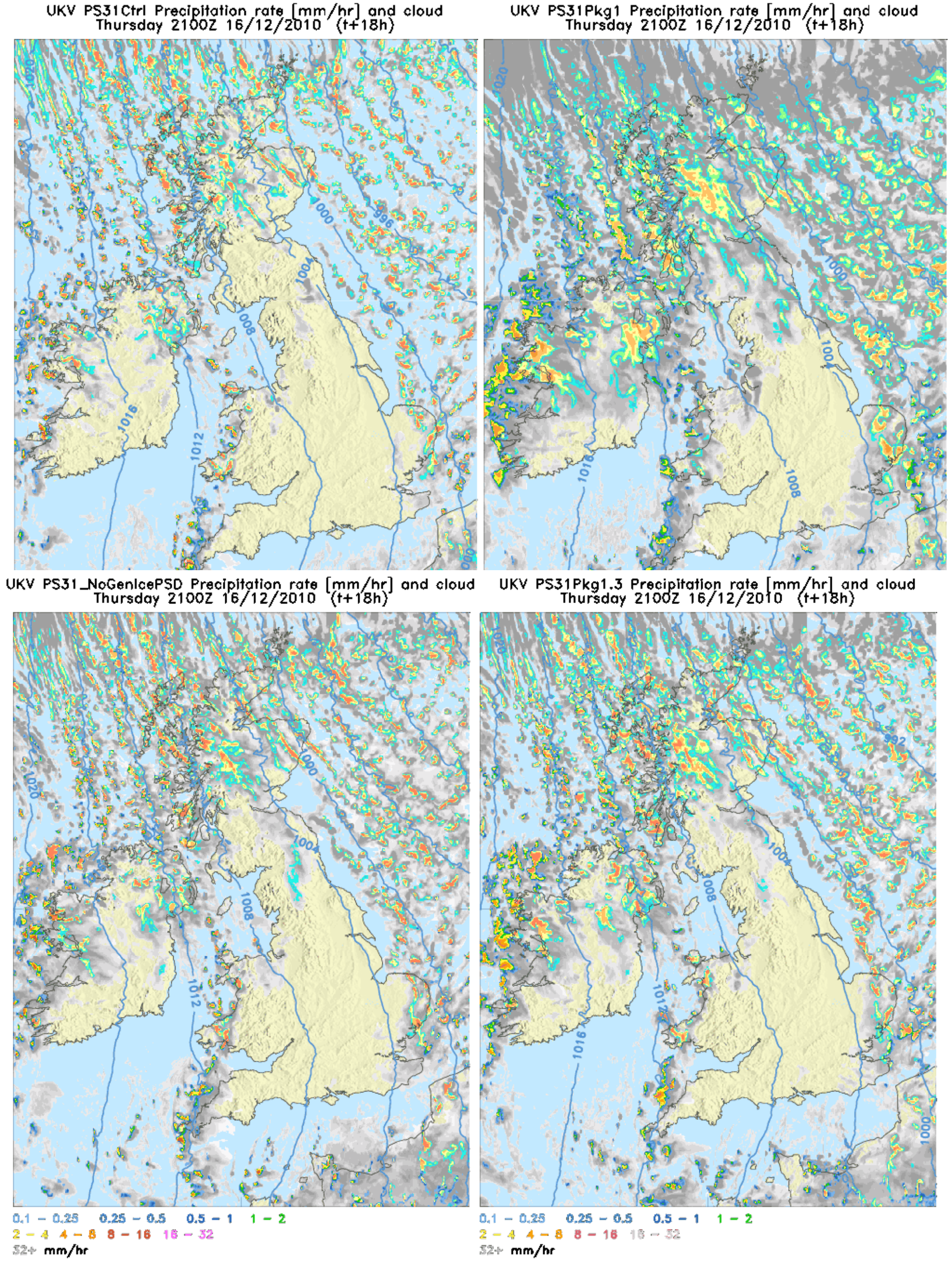
New ice PSD

PS29

New ice PSD

Fallspeed to low

Poor rainfall



PS27

Old ice PSD

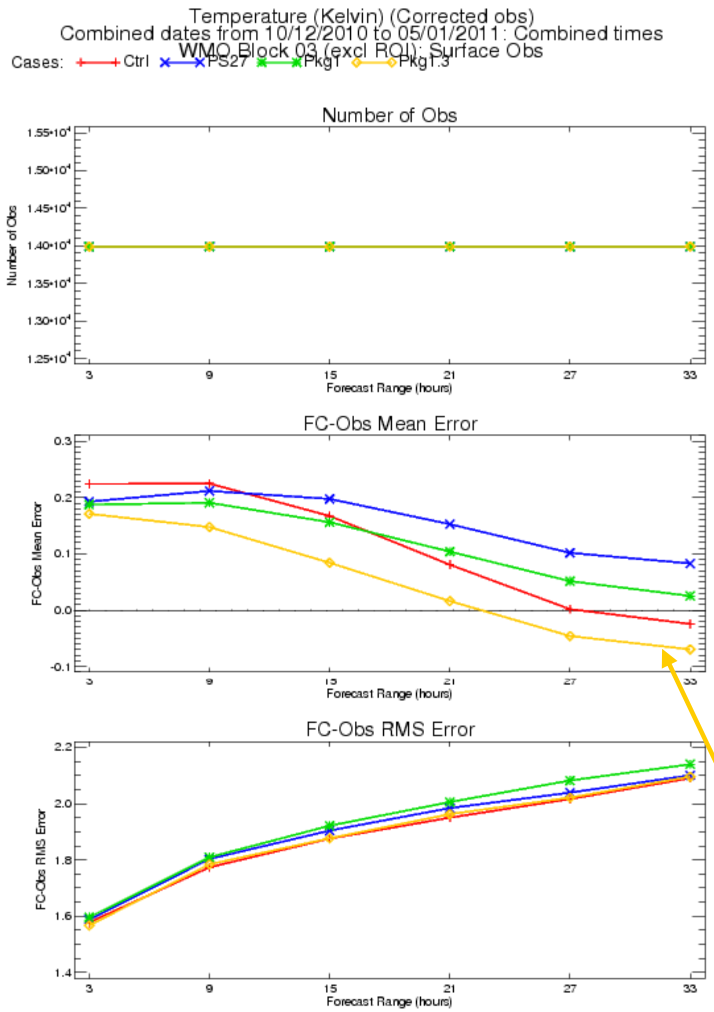
PS31

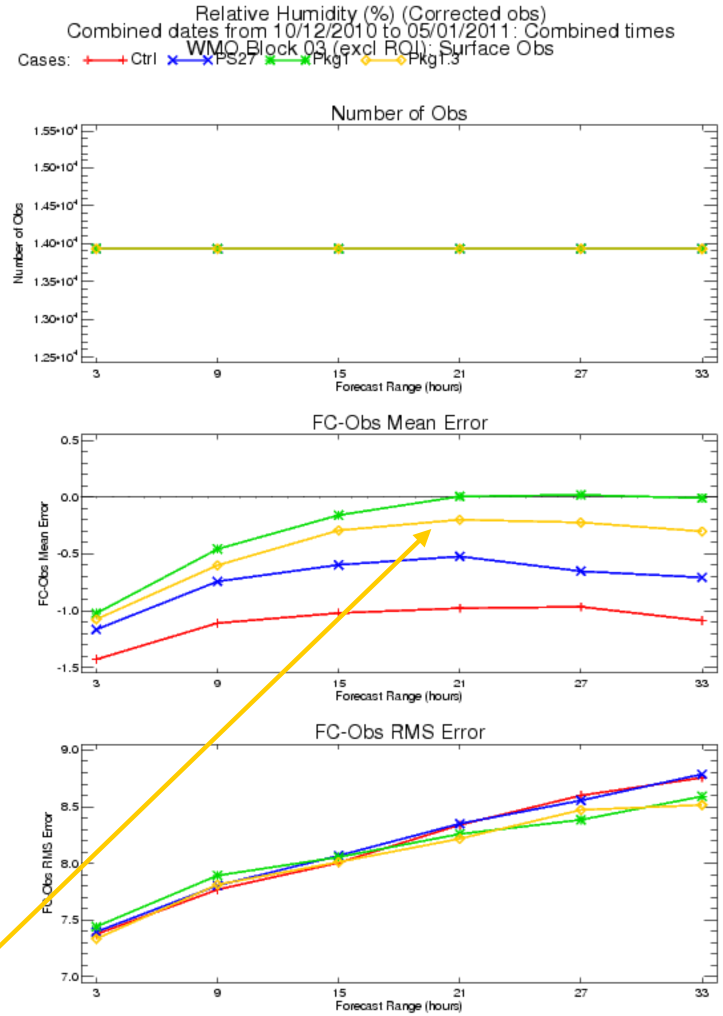
New ice PSD

Reduced Ice Fallspeed: Impact on T & RH

Screen temperature

Screen RH





Bias

RMSE

PS31 is cooler and moister
Maybe a rather complicated balance between SW and LW effects dependent on cirrus thickness

Misleading verification

- The cloud cover verification was being done against automatic obs (ceilometer data)
- The ceilometers cannot see above 6km
- Unfortunately the model was producing cirrus cloud above 6km and so the verification was not comparing like with like
- Hence there were spurious hits, false alarms, misses and correct rejections

New Cloud diagnostic

• Uses only the lower 6 km (ceilometer range) for the calculation of fraction cloud cover.

• Consistency of model output and observations for verification purposes.

• No downstream impacts as it is only used for verification. (UKPP, NAME and DA use cloud in model levels).

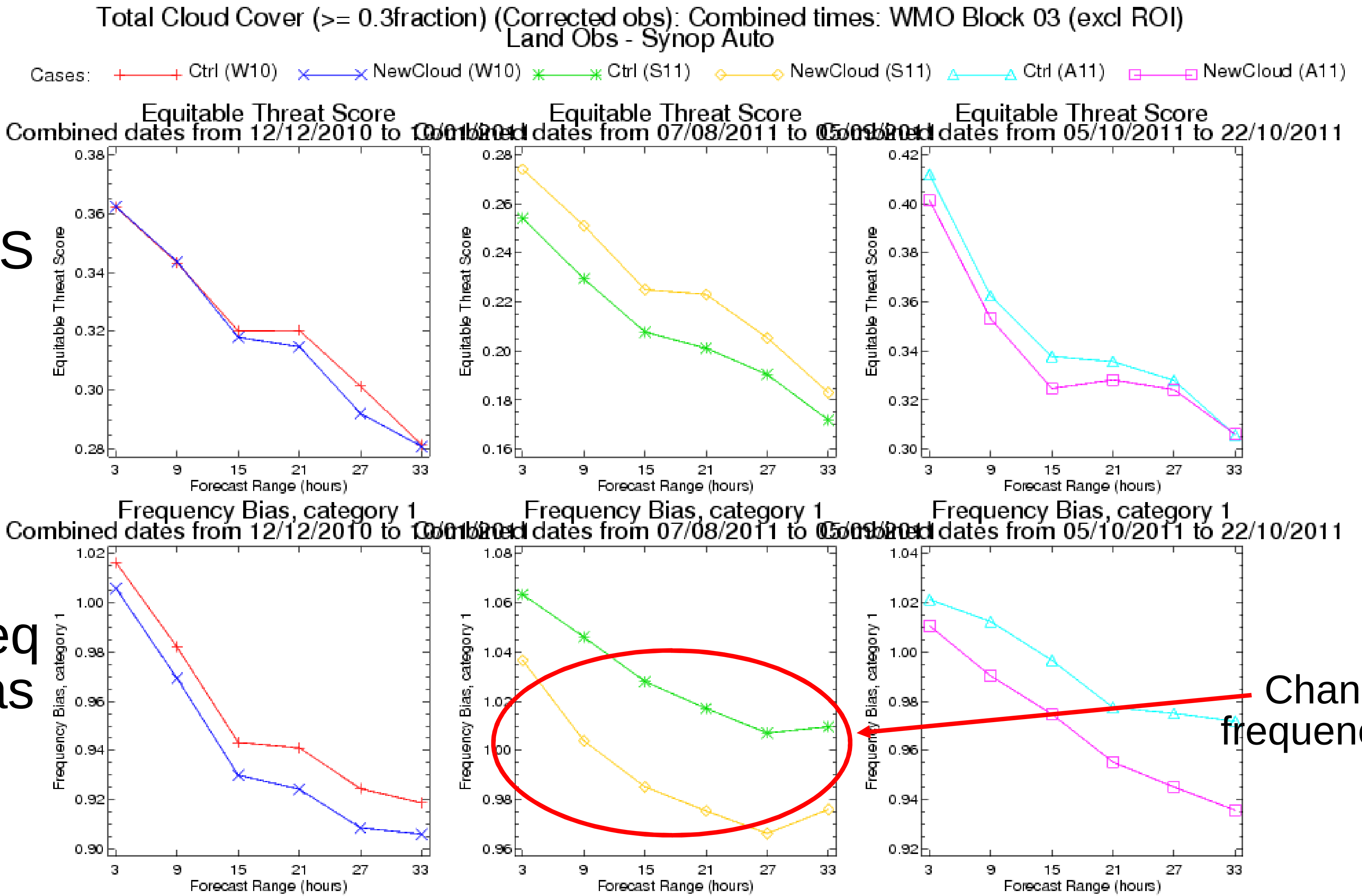
• Temporary solution. A new set of cloud observations based on Satellite Cloud Mask is in advanced state of research and will replace ceilometers.

New Cloud diagnostic: Total cloud cover

Winter | Summer | Autumn

ETS

Freq Bias



Changed frequency bias

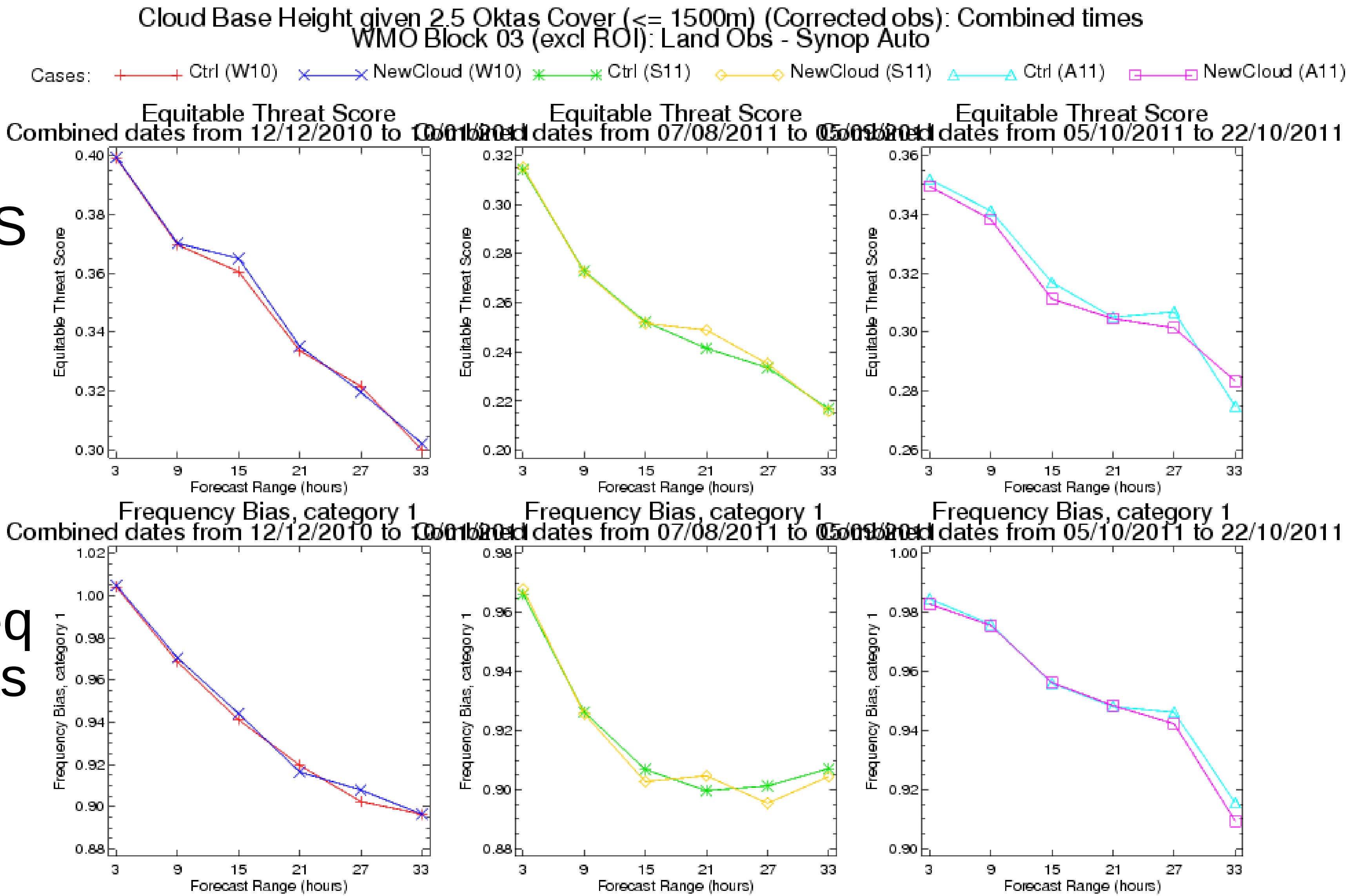
(

New Cloud diagnostic: Cloud Base Height

Winter Summer Autumn

ETS

Freq Bias



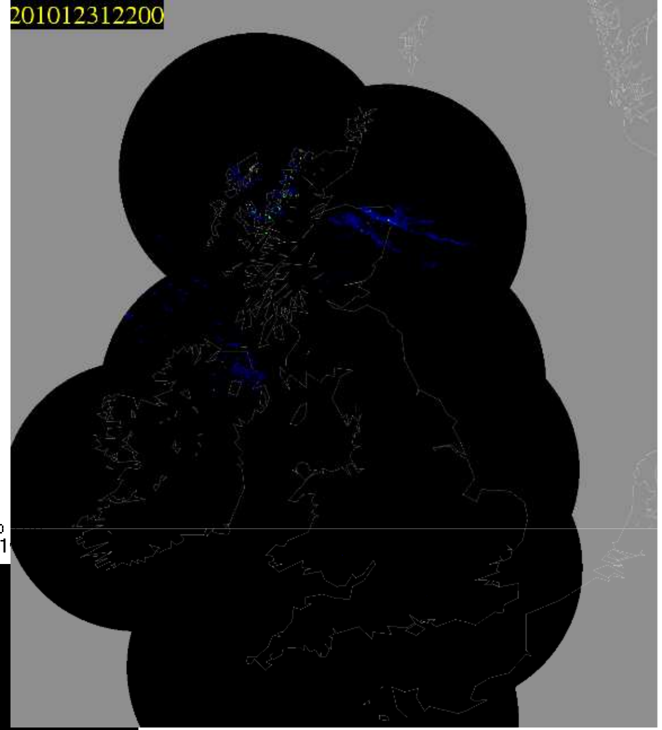
New Rain PSD

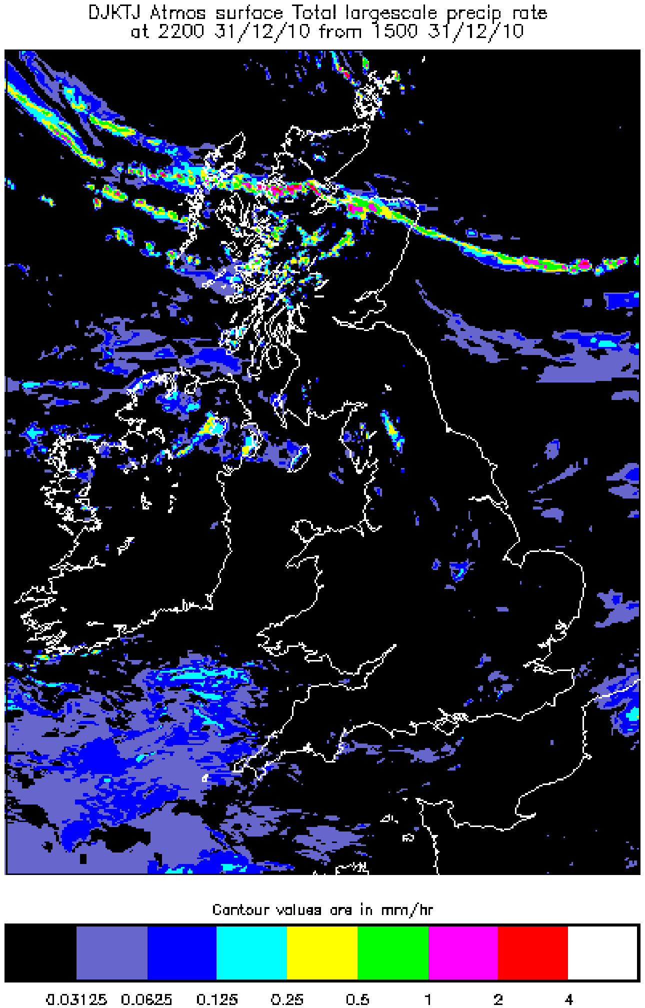
- Abel and Boutle (2012). An improved representation of the raindrop size distribution for single moment microphysics schemes. QJRMS, 2012
- Lots of observational data including the VOCALS campaign.
- Increases the number of small drops.
- These evaporate quicker and result in less drizzle
- Marginal impact in subjective assessment and verification scores
- Hard to evaluate against radar as a lot of drizzle falls below the radar beam

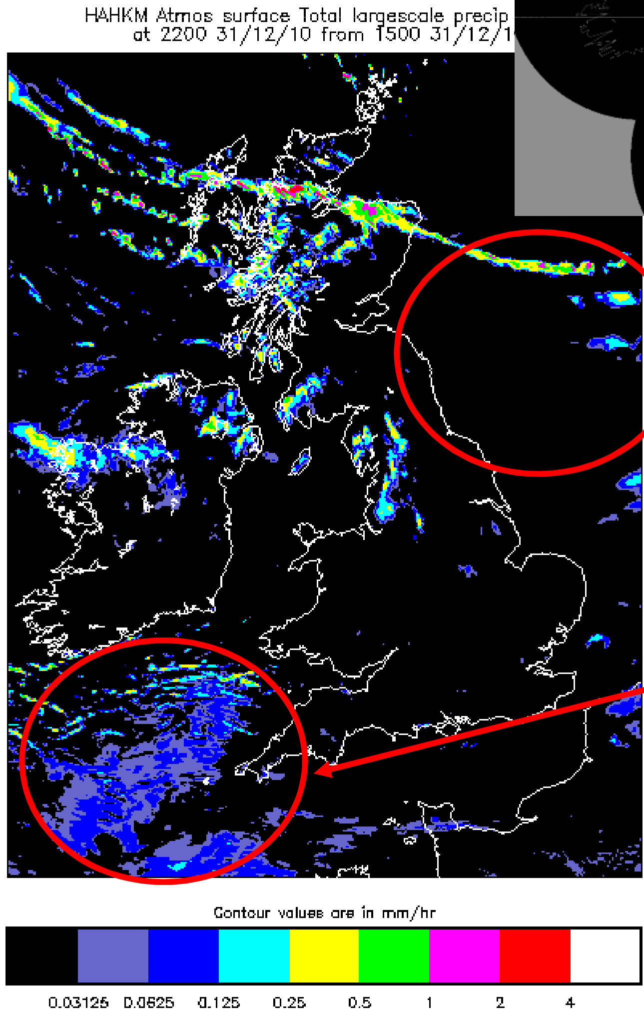
New Rain PSD

Met Office

radar







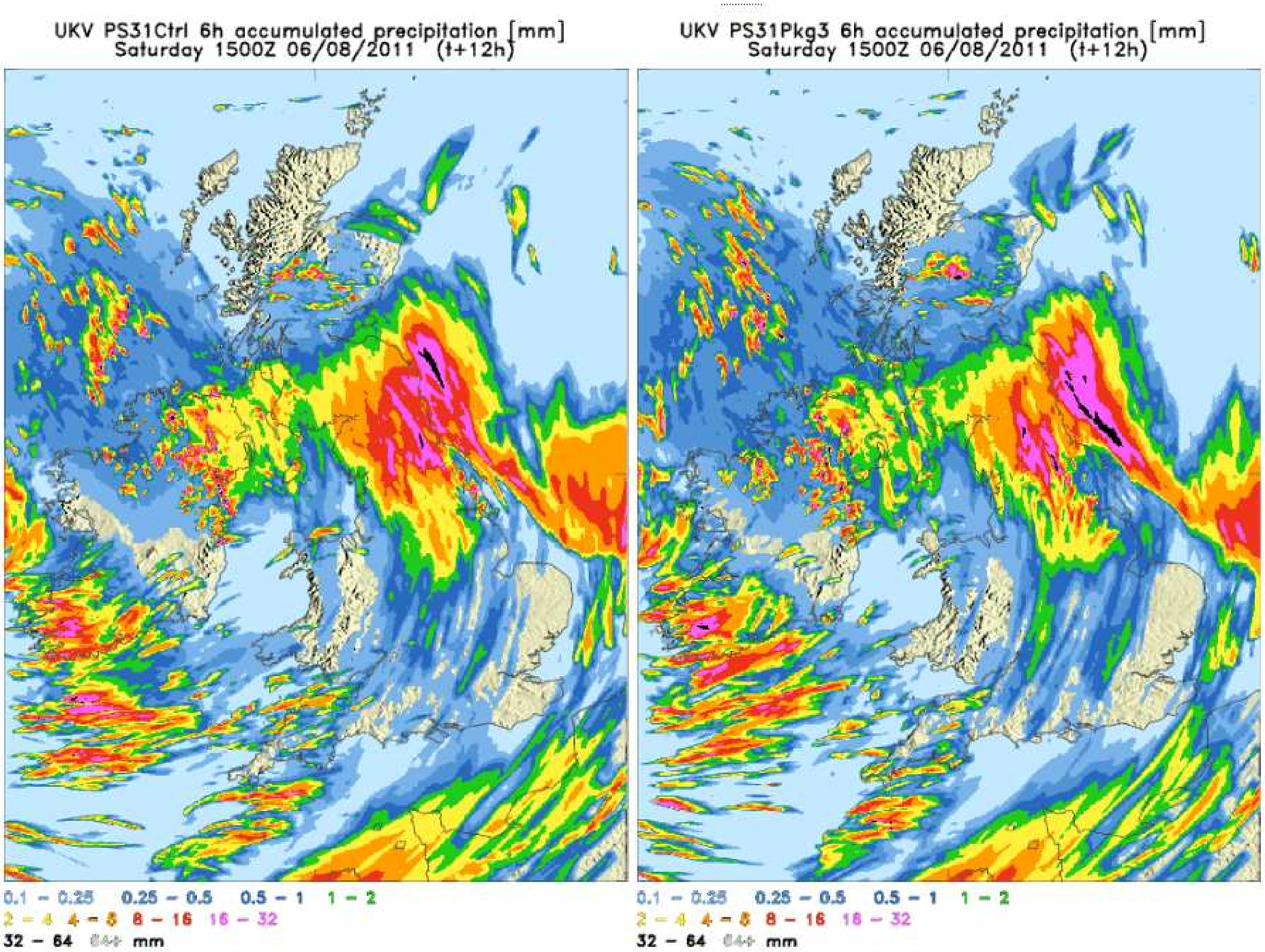
Less light rain

Prognostic Graupel

- The prognostic representation of graupel allows the representation of ice in the form of graupel, which can occur in deep convective cells.
- It acts as an efficient moisture sink due to having a high fall speed relative to rain and snow.
- Needed for lightning diagnostic.
- E.W. McCaul, S. J. Goodman, K. M. LaCasse & D. J. Cecil, 2009: Forecasting lightning threat using cloud-resolving model simulations. Wea. Forecasting, 24, 709-729.

Prognostic Graupel

Marginal impact, both in subjective assessment and in verification scores

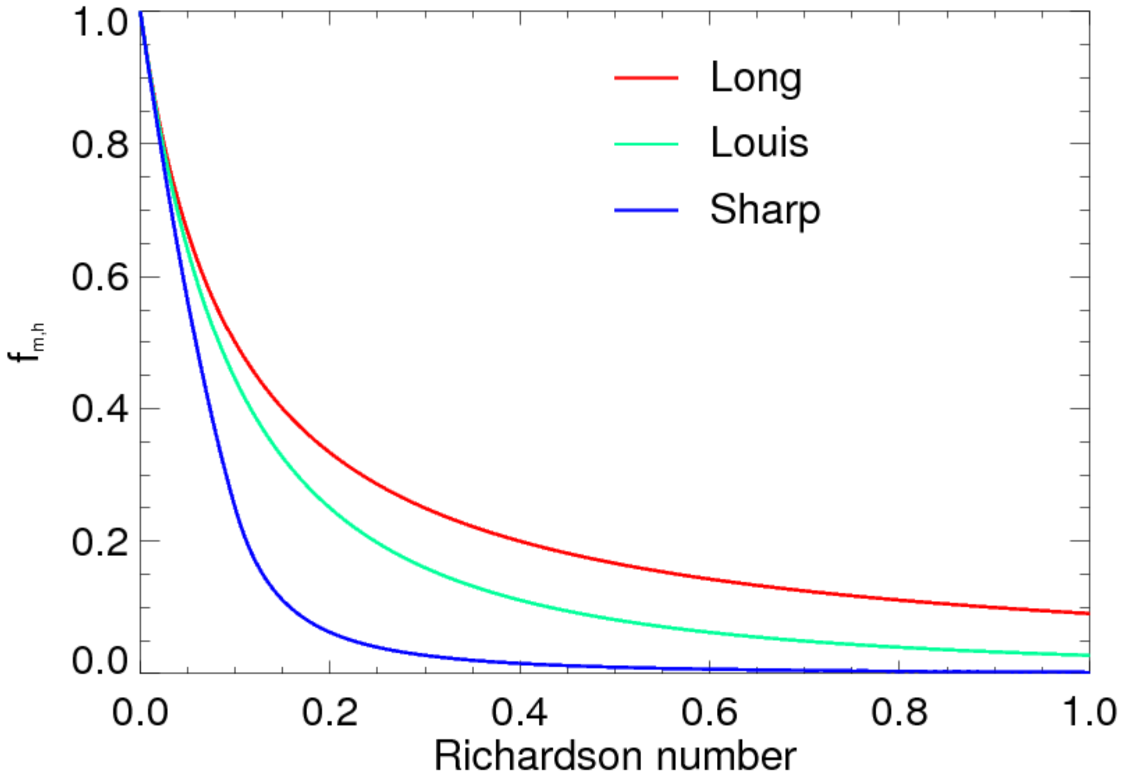


Stable Boundary layer changes

- Use the screen temperature over the grass tile for verification (where more than 5 % of gridbox is grass), instead of grid-box mean
- Sharpest tails (instead of Mes over land)
- LEM conventional stability functions for unstable conditions (gives weaker mixing from the local scheme)
- Stability dependent Prandtl number for stable boundary layers (ratio of momentum to heat diffusion) to give relatively more momentum mixing as stability increases due to gravity waves
- Surface emissivity varying from 0.9 to 0.99 with surface type, instead of all 0.97

Stable Boundary layer tails

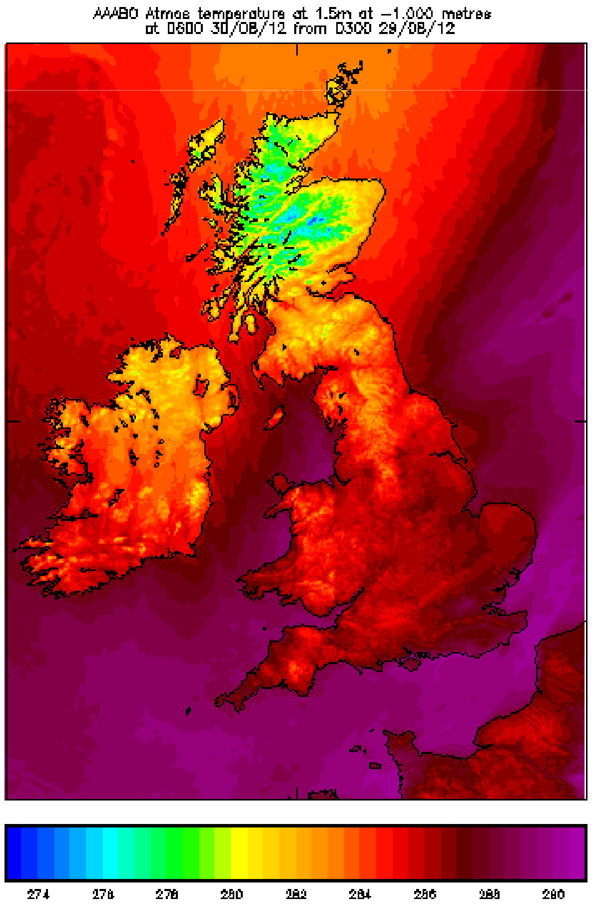
- Control is Mes tails over land or “Sharp-Louis combo”
- That is Louis at the surface, Sharp at 200m and a linear interpolation between the two in between
- The new formulation is Sharp all the way up
- Therefore the biggest difference with control is at the surface

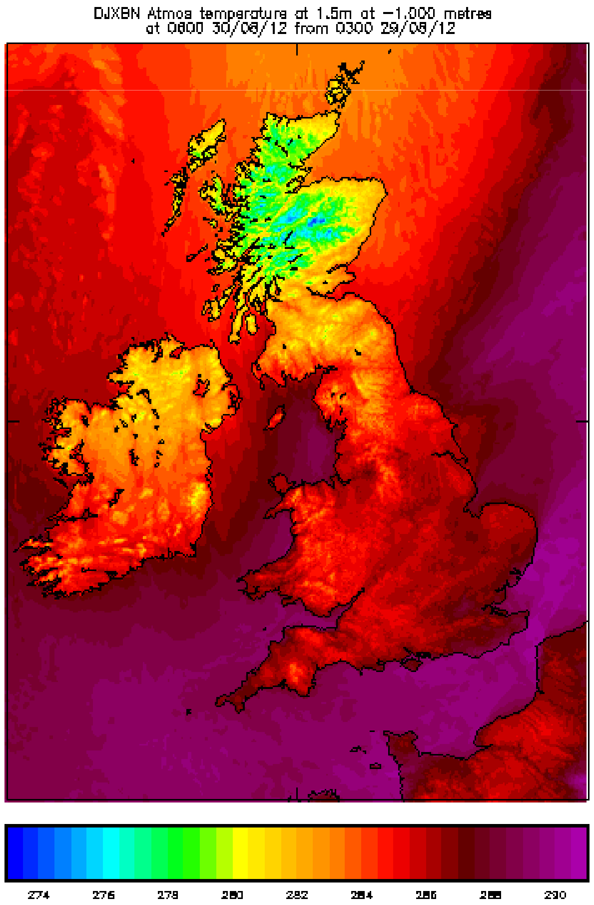


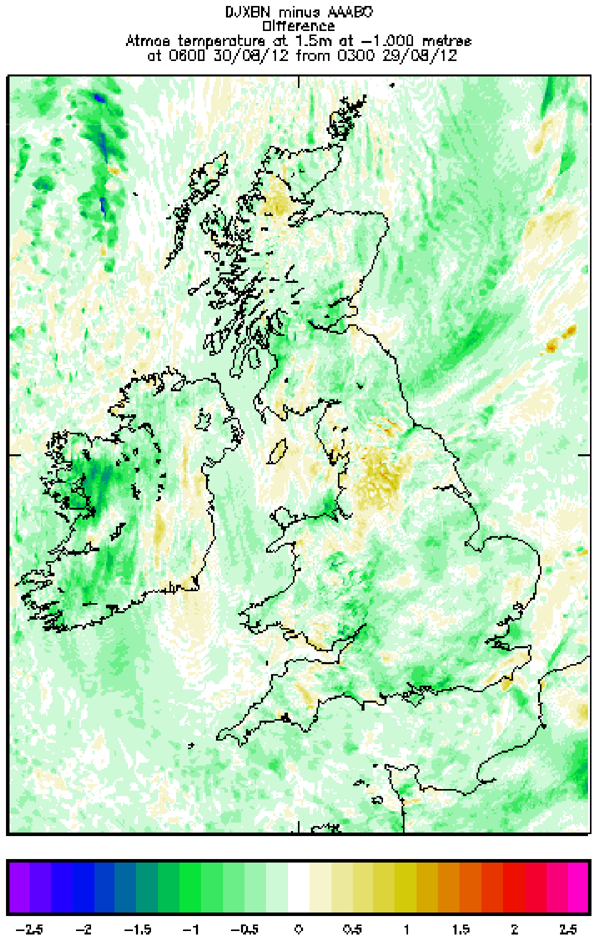
Impact of Stable Boundary layer changes

- Reduces mixing in stable conditions.
- To tackle underforecasting of minima in stable winter nights.
- Improves RH and Temperature in stable nights.
- Causes overforecasting of winter fog

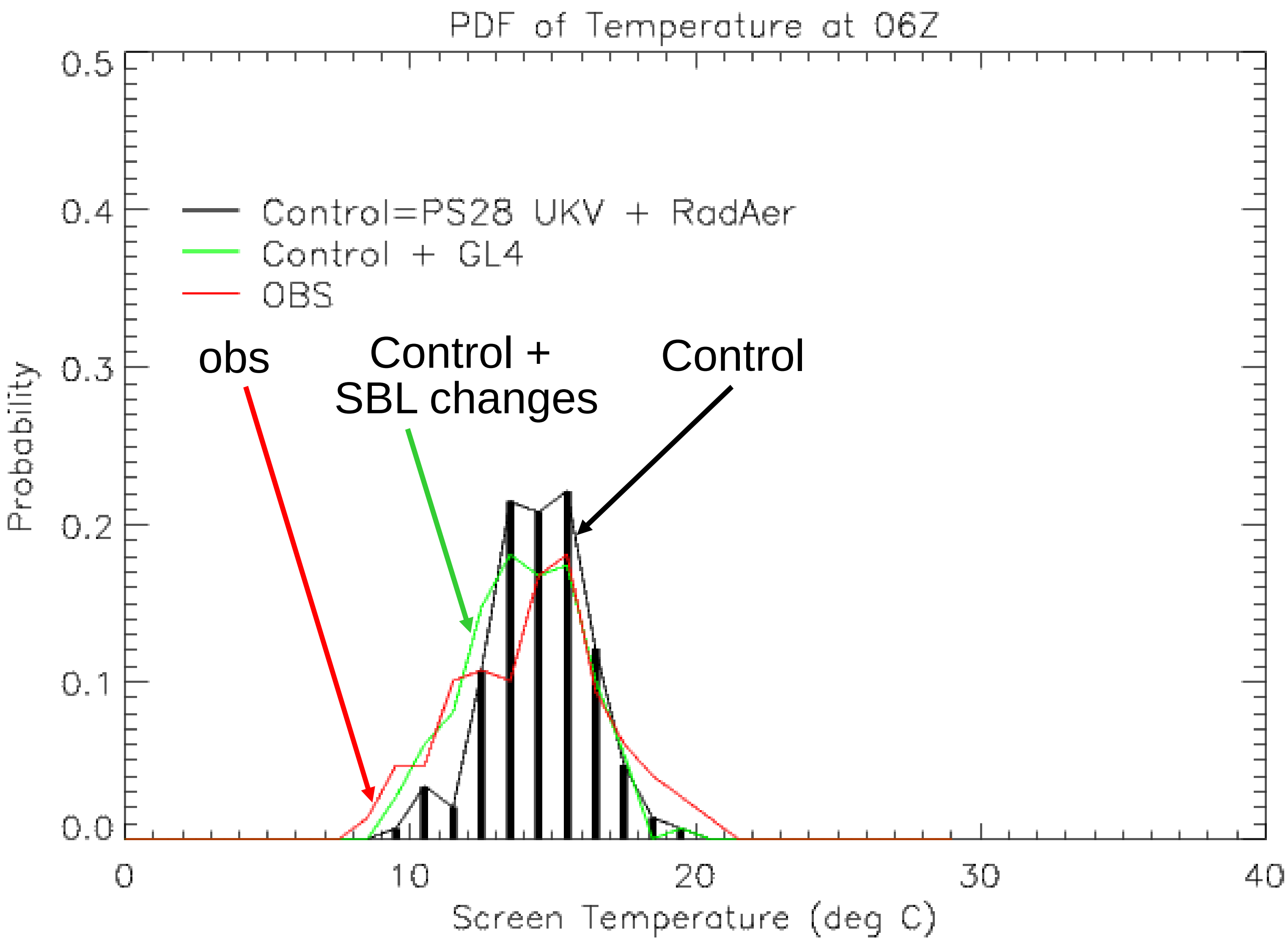
Stable Boundary Layer changes: 06Z temperatures.





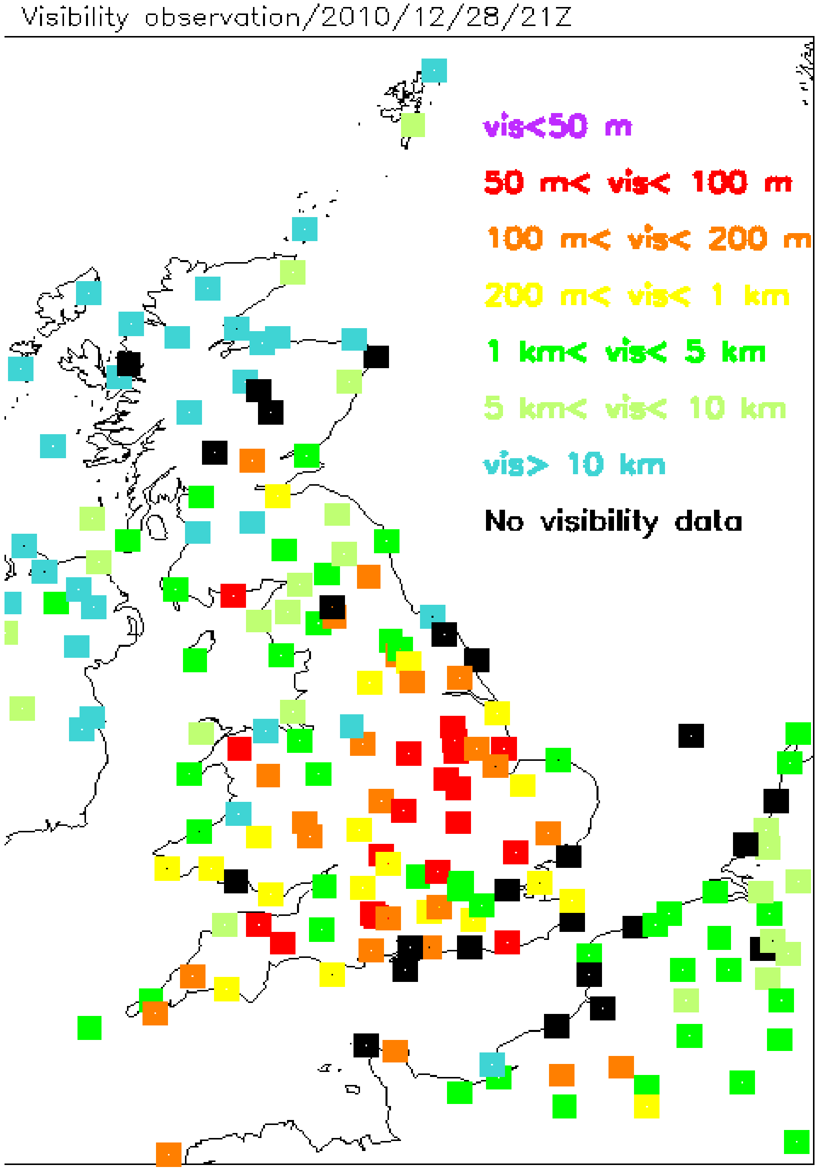


Stable Boundary Layer changes: 06Z temperatures

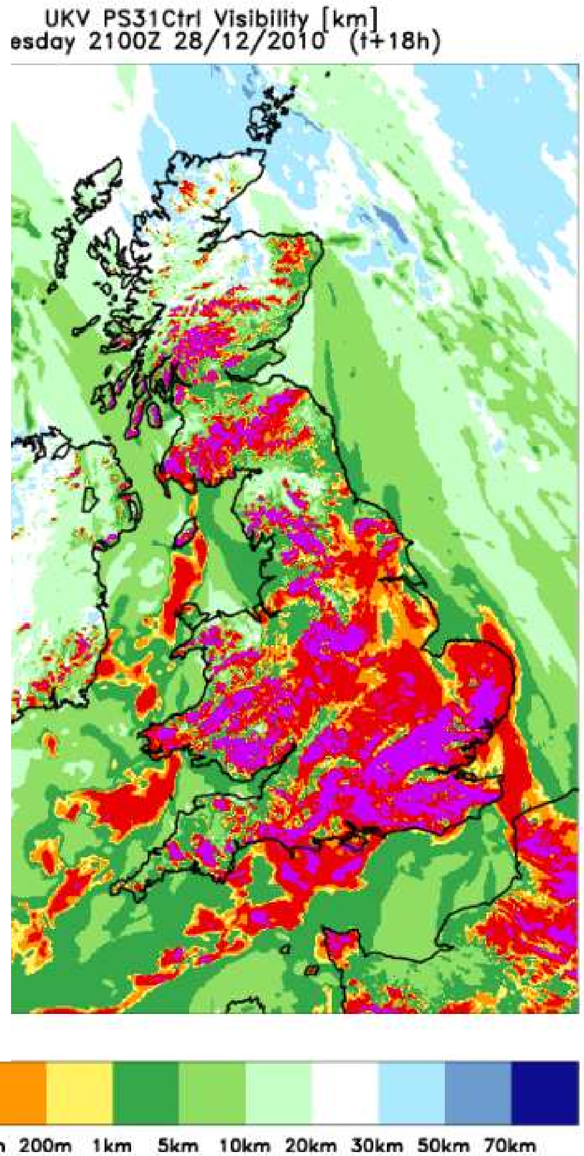


Courtesy: Aurore Porson

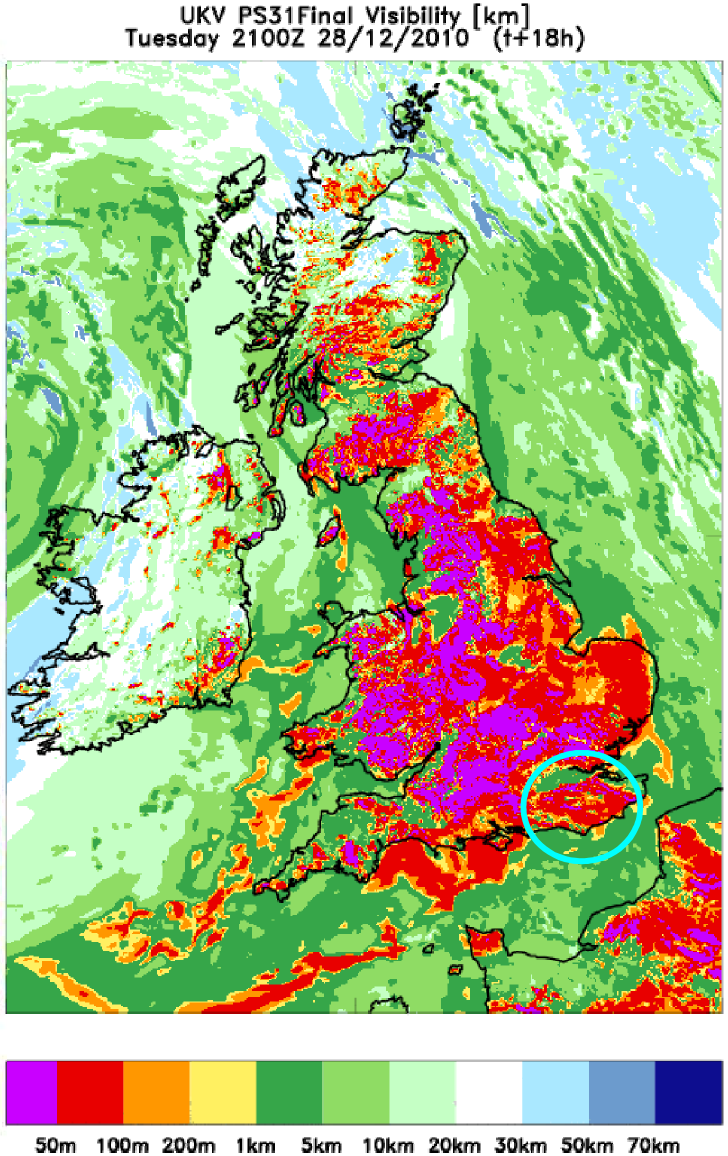
Stable Boundary Layer changes: Visibility
Extensive fog episode, 28-29th Dec 2010: 21Z



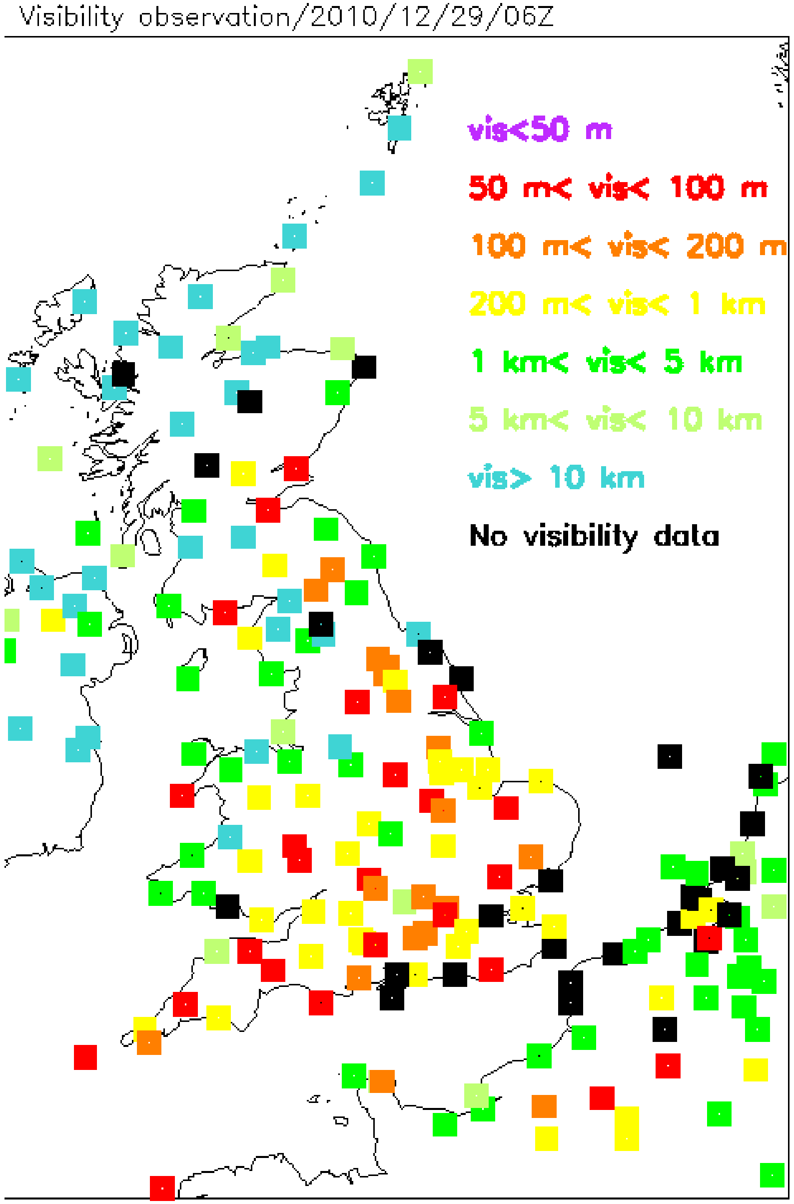
Op model



PS31

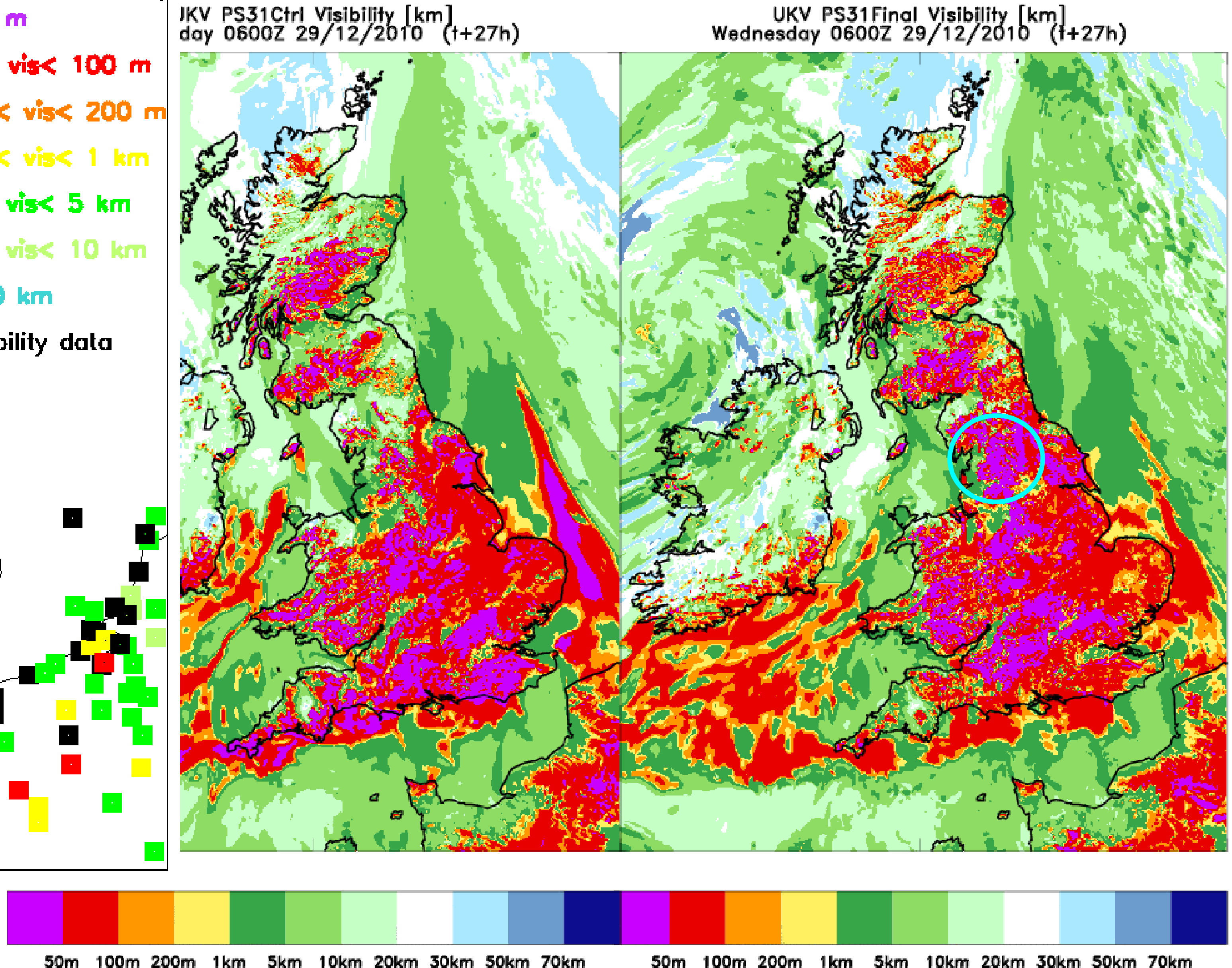


Stable Boundary Layer changes: Visibility
Extensive fog episode, 28-29th Dec 2010: 06Z

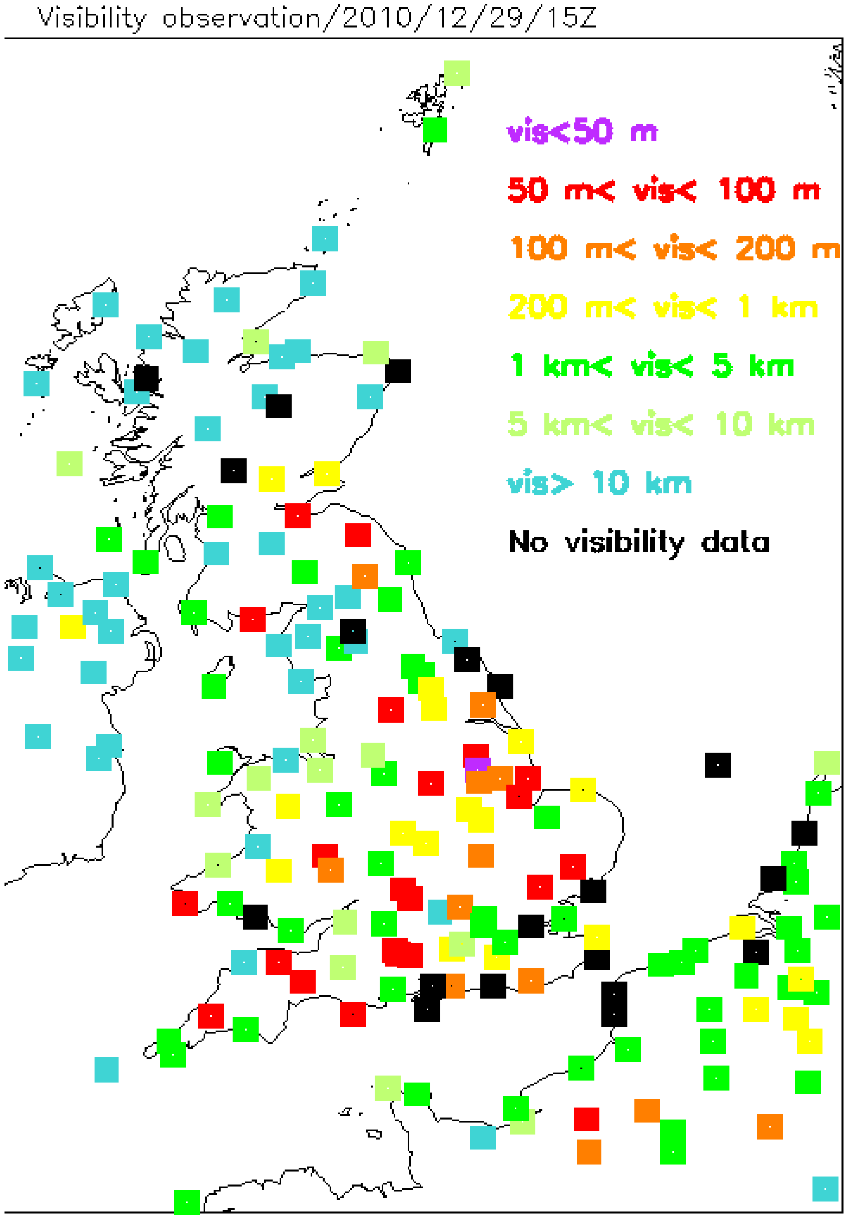


Op model

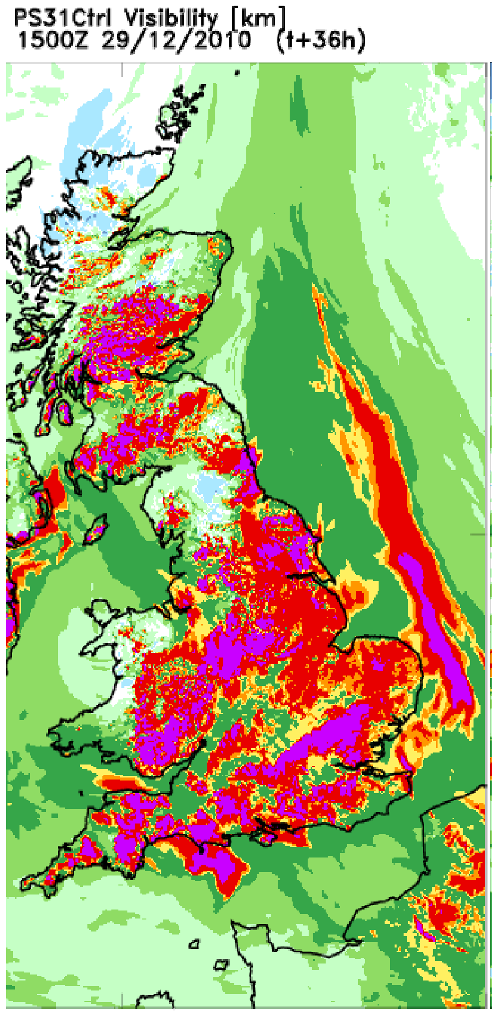
PS31



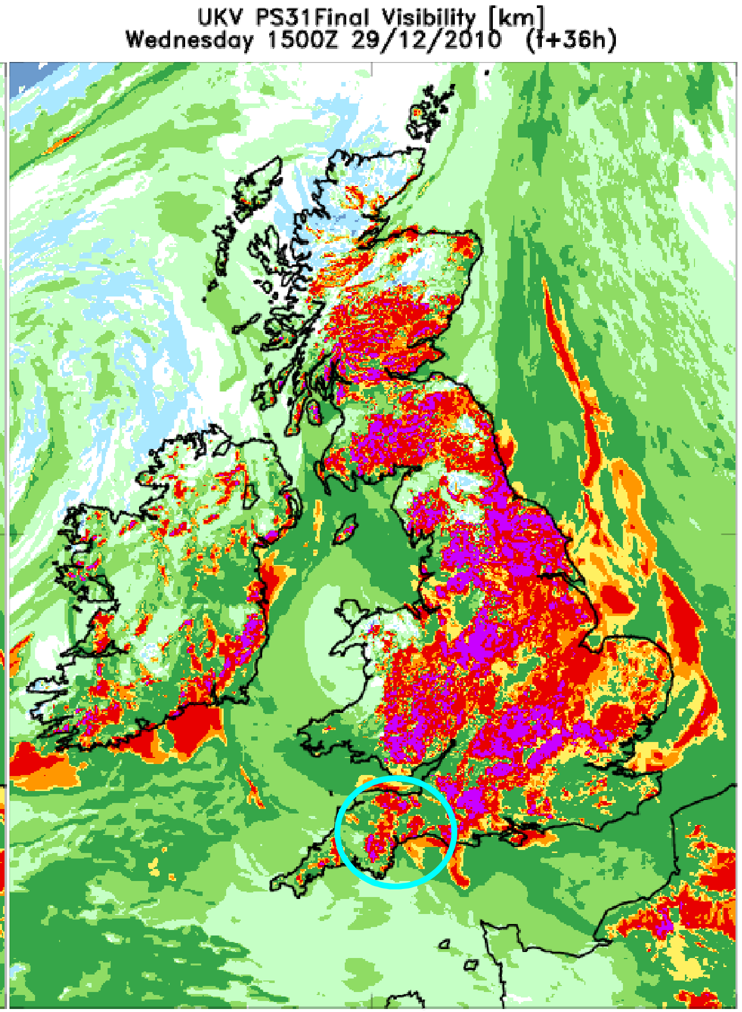
Stable Boundary Layer changes: Visibility
Extensive fog episode, 28-29th Dec 2010: 15Z

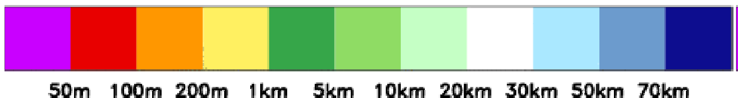


Op model



PS31

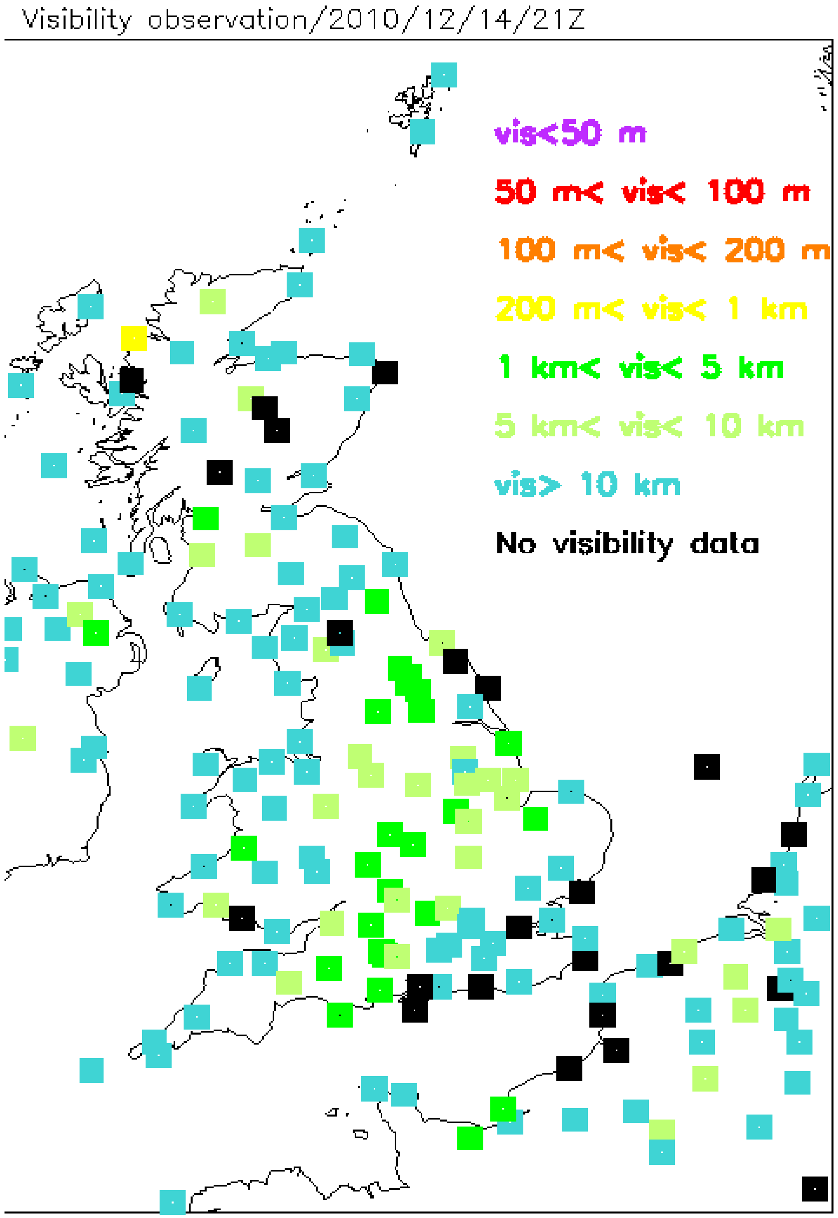




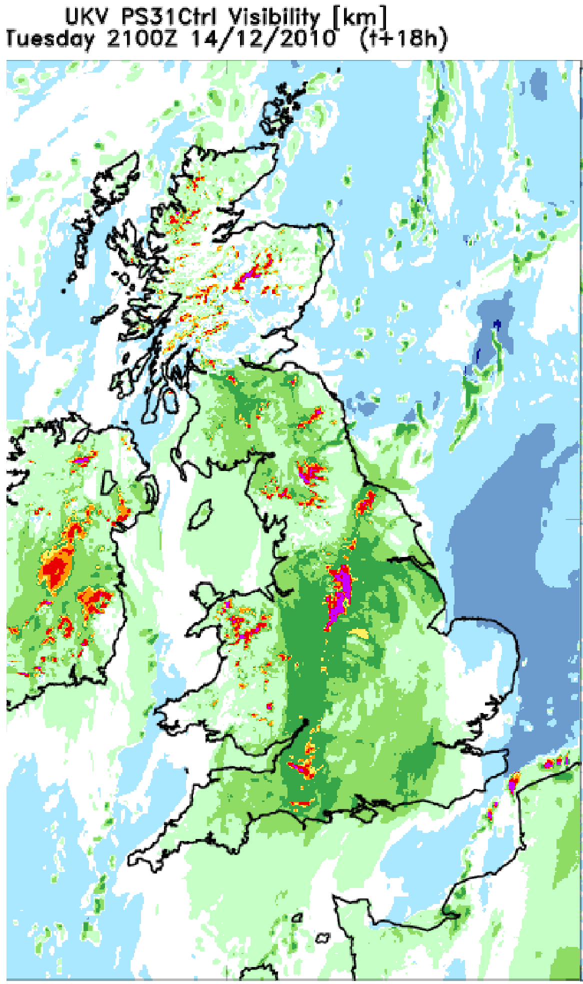
Localised fog episode, 14-15th Dec 2010

- More fog in proposed PS31 package
  - But associated with a change in the evolution of low cloud and showers off the North Sea?
  - Admittedly frequency bias will be higher for this case
  - But main signal doesn't look too bad against satellite though

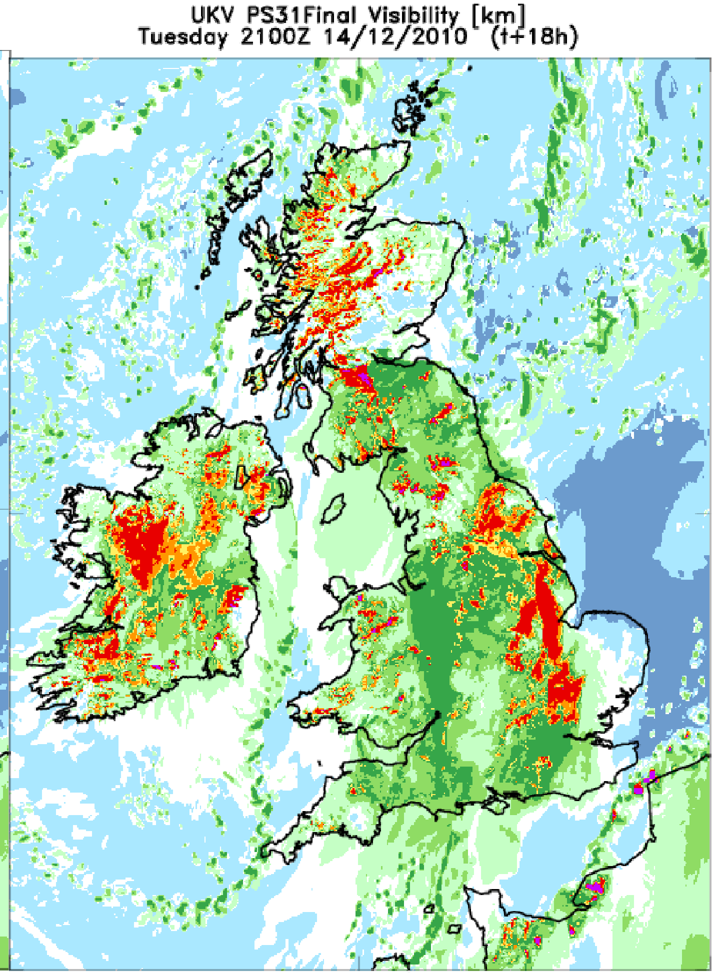
Stable Boundary Layer changes: Visibility
Localised fog episode, 14-15th Dec 2010: 21Z

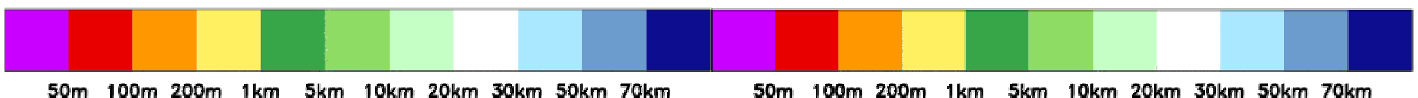


Op model

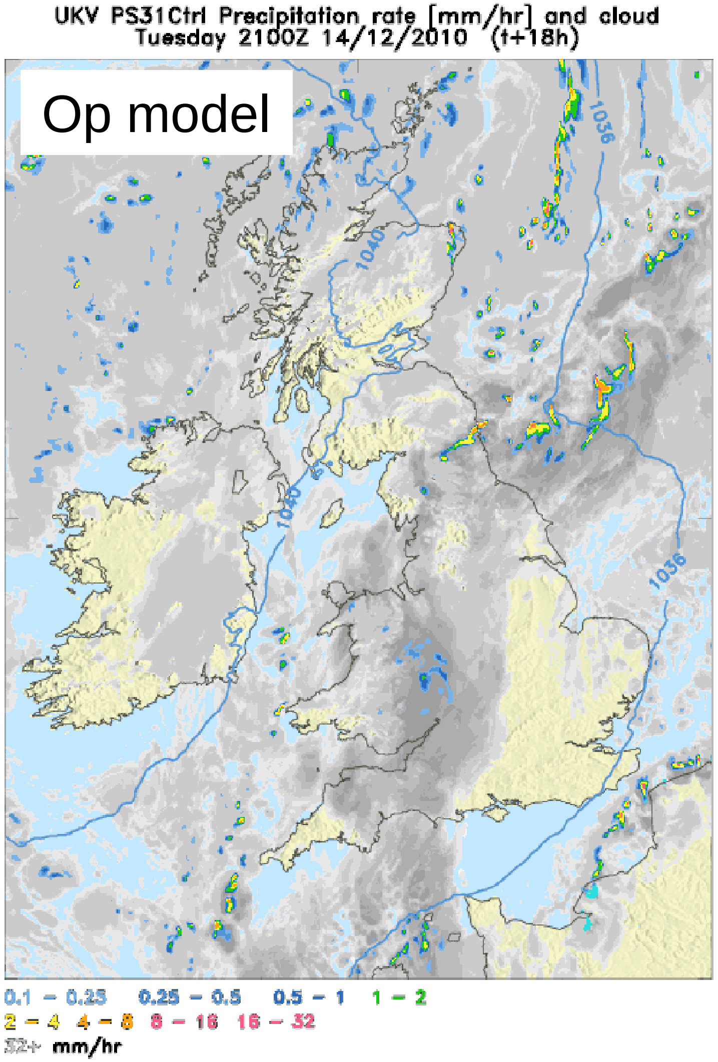


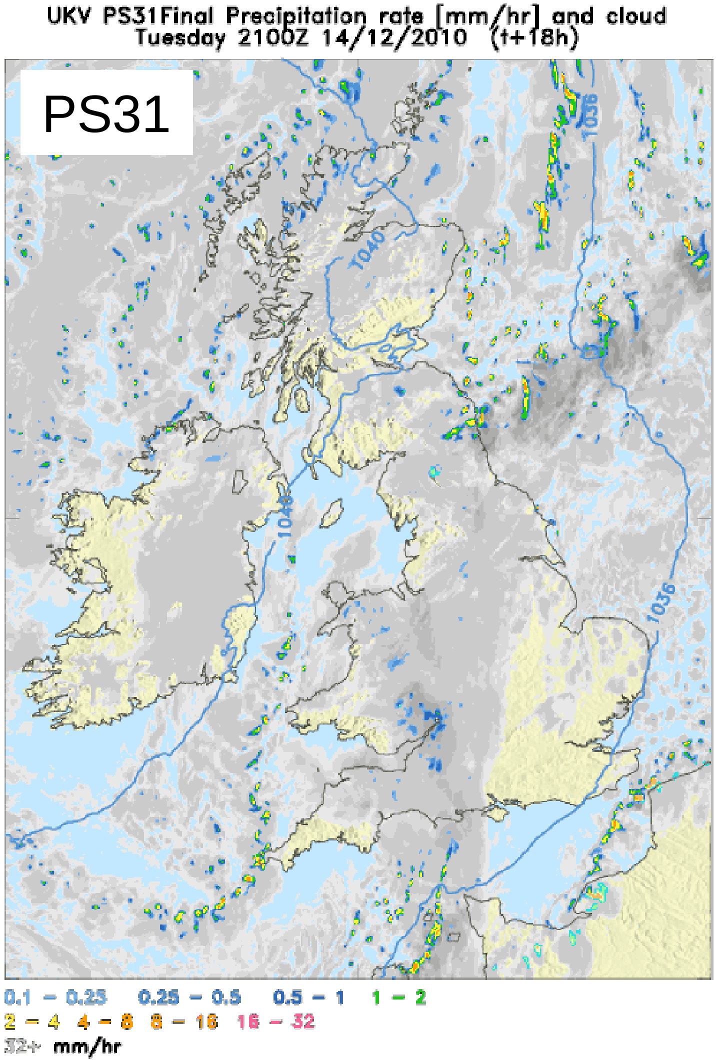
PS31





Stable Boundary Layer changes: Visibility
Localised fog episode, 14-15th Dec 2010: 21Z



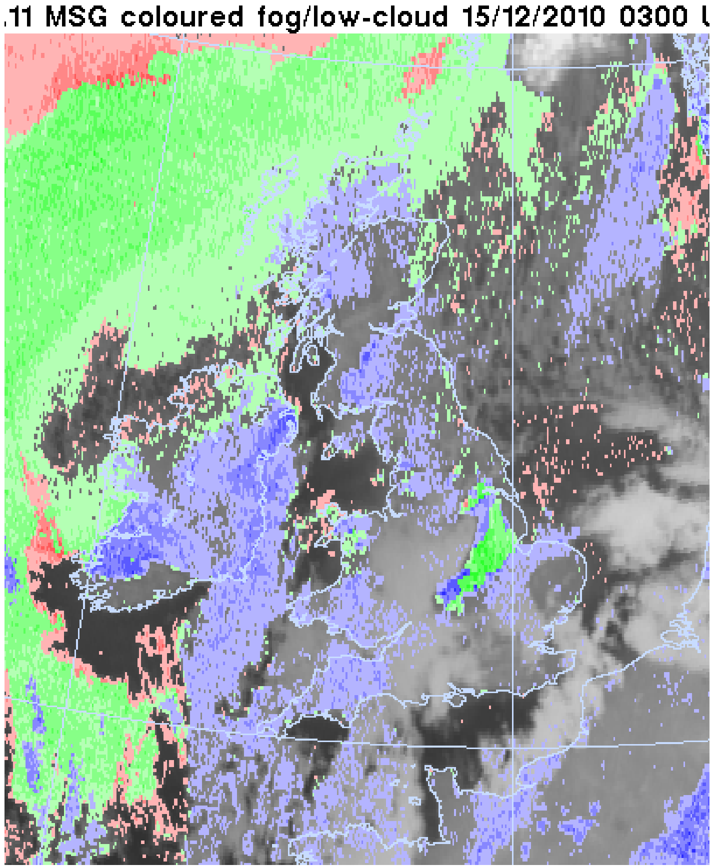


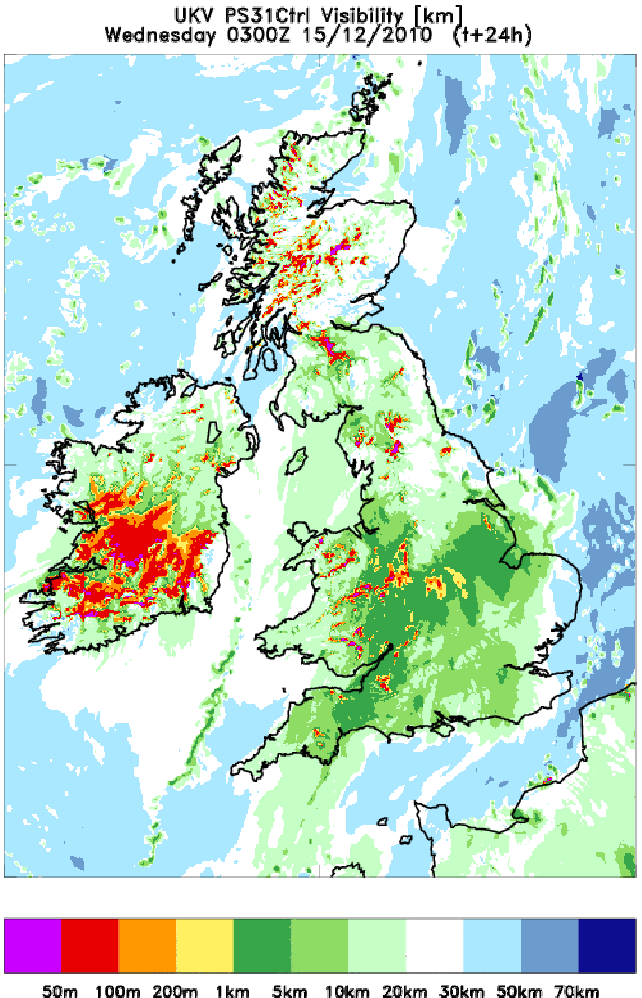
Stable Boundary Layer changes: Visibility
Localised fog episode, 14-15th Dec 2010: 03Z

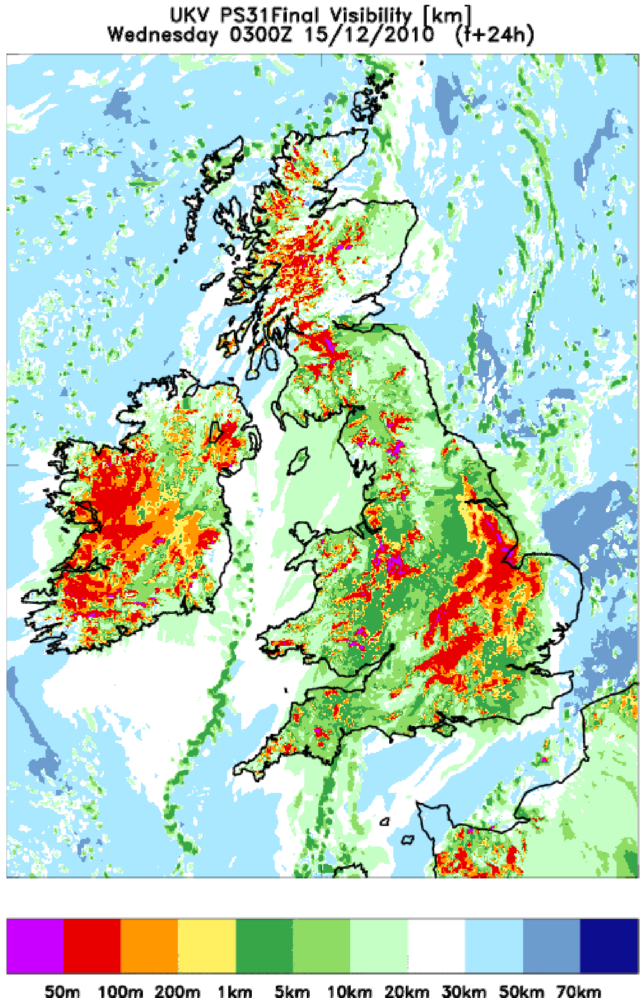
Met Office

Op model

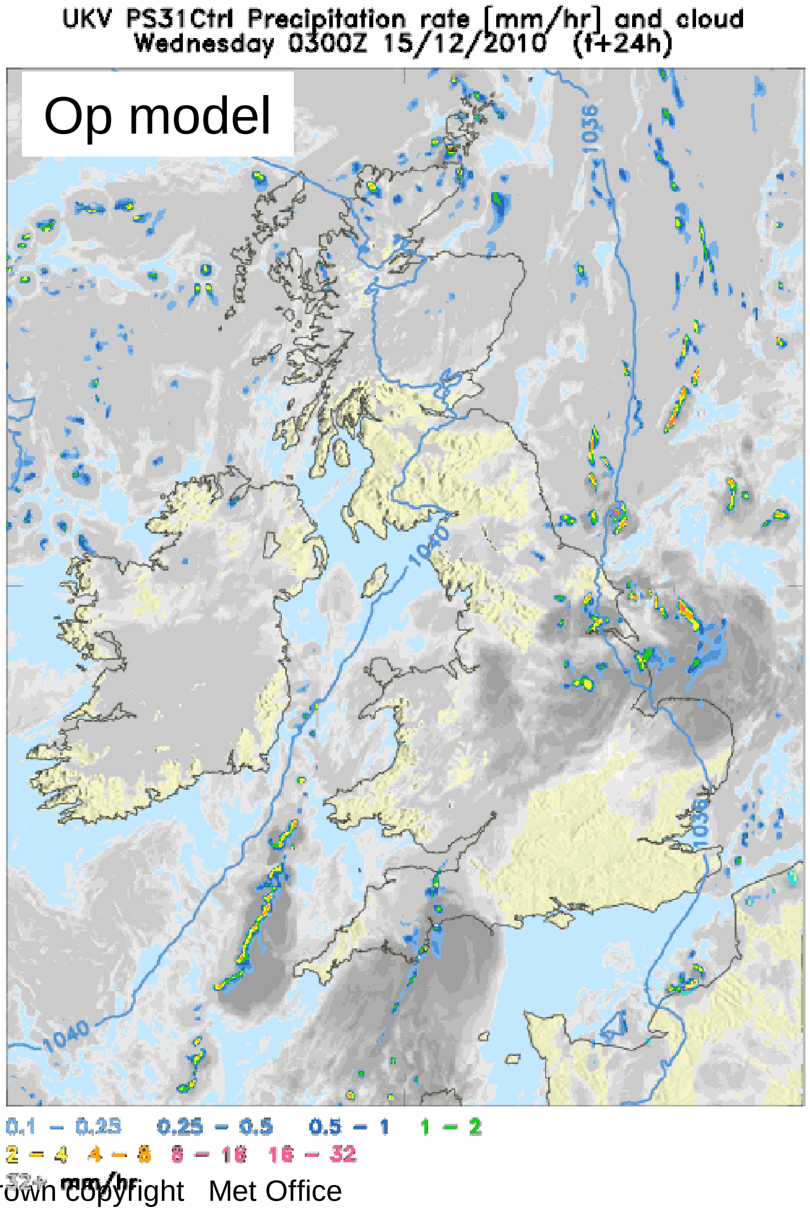
PS31

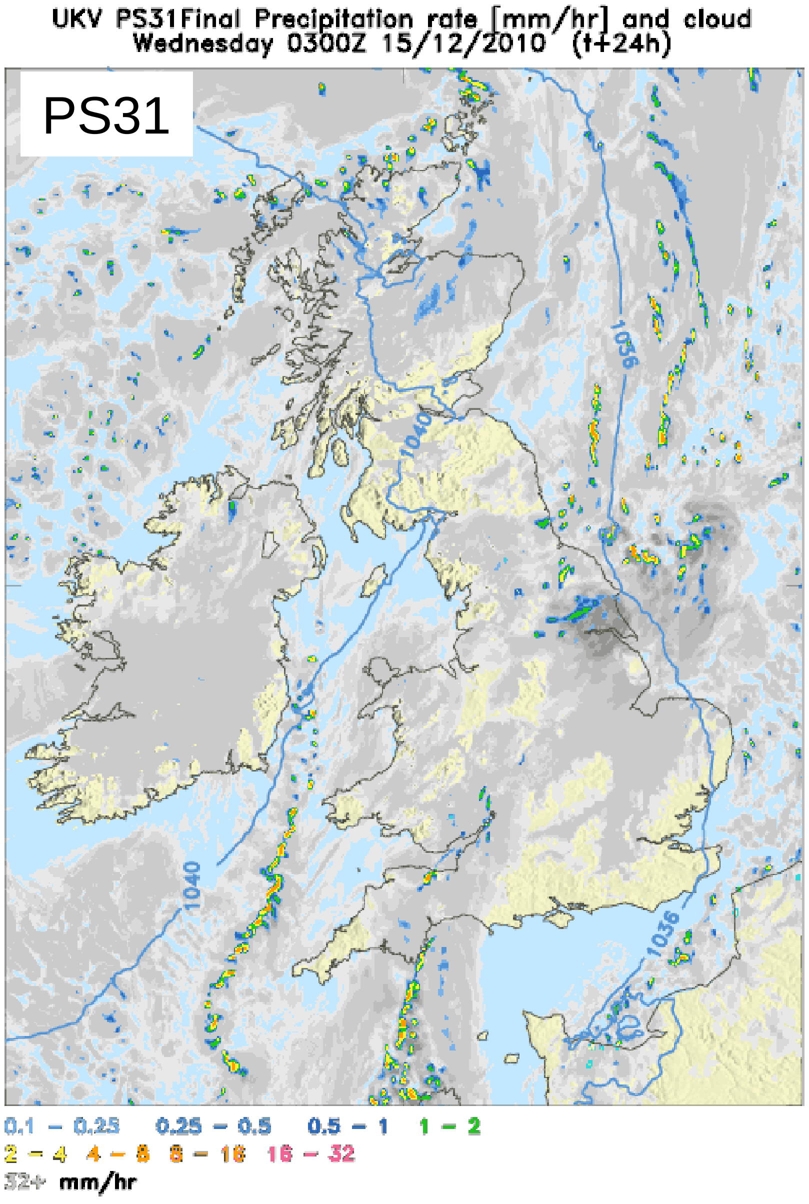






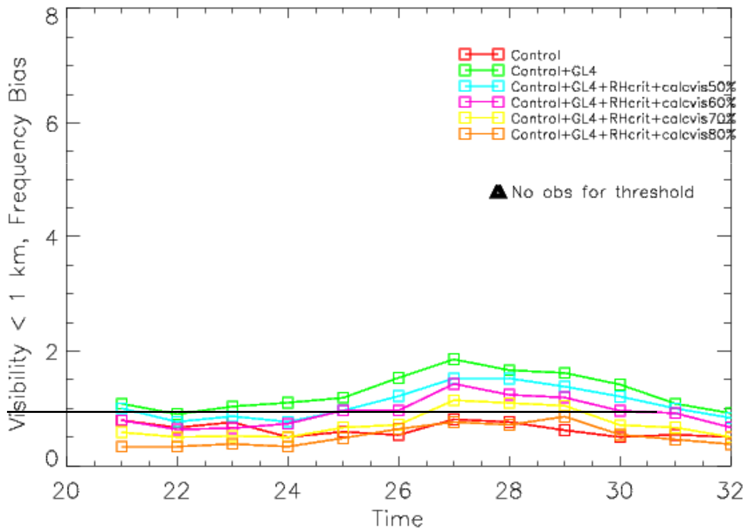
Stable Boundary Layer changes: Visibility Localised fog episode, 14-15th Dec 2010: 03Z





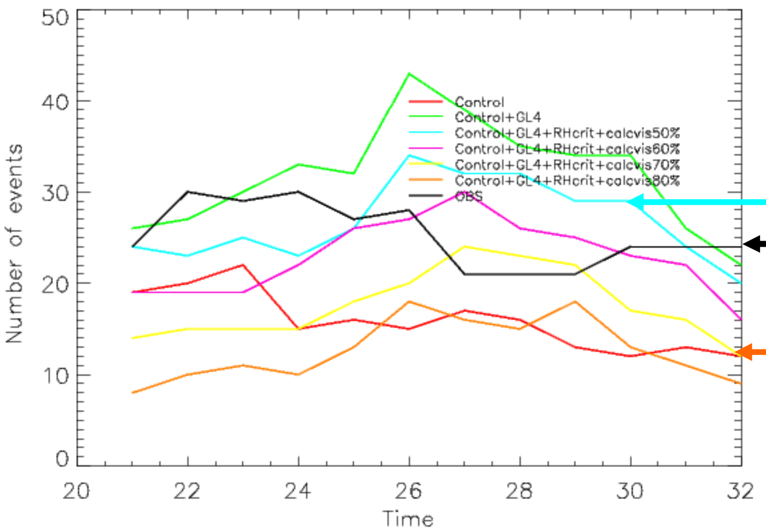
Retune the fog diagnostic?

Vis Frequency bias



Potential change to vis diagnostic if increase in Frequency bias really thought to be bad

Vis Number of events



PS31

obs

Op model

Summary of performance

- High cloud restored without adverse effects on other variables.
- Proposed changes produce lower screen temperatures
- Better at night time but worse at day time. Overall skill slightly detrimental.
- Relative humidity improved by reducing a dry bias.
- Winter fog is increased.
- Further work required to mitigate fog signal before the changes can go operational

Questions

Microphysics schemes and the UM

- The PSD calculates moments needed in the transfer rates calculations
- Examples are:
- M1->1.5 Diffusional growth
- M2 Mass
- M2.5 Sedimentation, riming
- M4 radar reflectivity (when we do data assimilation)

Fallspeed relationship

- The Best Number is defined as $X = C_D \mathrm{Re}^2 = \frac{2mg\rho_a D^2}{A\eta^2}$ where m is the particle mass, g is the gravitational acceleration, rho is the air density, D is the maximum dimension of the particle, A is the area project to the flow and eta is the dynamic viscosity.

- The Reynolds number is related to the ratio of the inertial and viscous forces of a fluid moving around a body. The following empirical relation links Re with X:

  Re = aX^b with a=0.0649 and b=0.831 (10 < X < 585)

- The following relations are used to relate mass and Area projected to the flow with D: $m = \alpha D^\beta$

  $A = \gamma D^\sigma$

- Given Vt = Re.eta/rho.D

- We get:

$$v_t = a\nu\left(\frac{2\alpha g}{\rho_a \nu^2 \gamma}\right)^b D^{b(\beta+2-\sigma)-1}$$

Stable Boundary layer changes

- correction to M-O calculation in the stable limit
- roughness lengths changed from [1,3e-4,3e-4,1e-4] to [1,1e-4,1e-3,5e-4] for [urban (no change), lakes (more consistent with Charnock for typical windspeeds), bare soil (consistent with GA4), ice (GA4)]
- ratio of z0h to z0m changed from 0.1 to 0.25 for lakes (consistent with sea parametrization), 0.02 for soil (observations over deserts) and 0.2 for ice (observations over ice)
- ratio of z0h to z0m also changed to 1.65 for tree tiles (from 0.1)
- implementation of an on-canopy snow depth (for roughness and albedo)