# Evaluation and improvement of a diagnostic cloud fraction scheme using ARM data

Met Office

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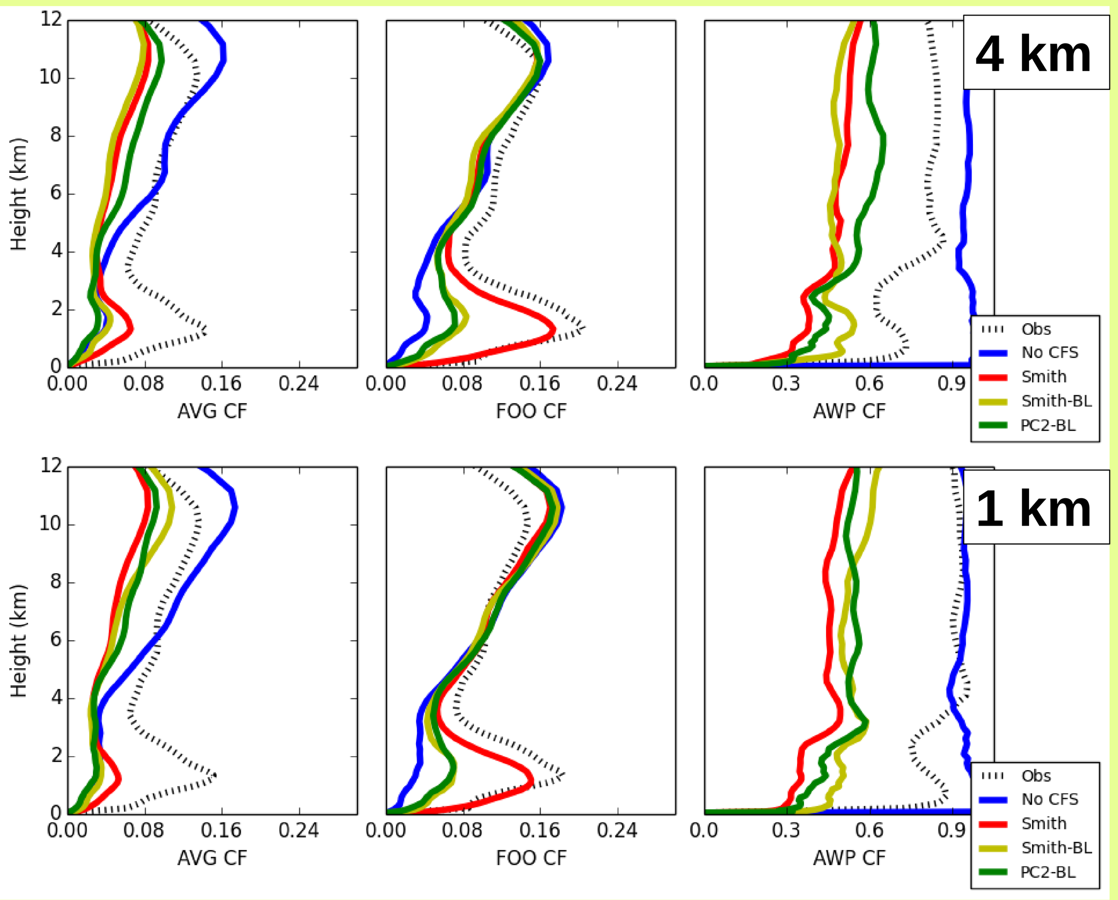
## Motivation

- Cloud fraction schemes (CFS) are used in GCMs to account for subgrid variability (important for radiation and microphysics).
- It is not known up to what resolution they are beneficial.




***Cloud fraction properties for convection-permitting simulations at 4 and 1 km grid spacing with three different CFS and without a CFS for Spring 2011***

AVG=average, FOO=frequency of occurrence, AWP=amount when present
Only non-precipitating and non-mixed phase cloud
Observations are from ARSCL/Microbase-KA VAP

***Current CFS do not converge to all-or-nothing schemes at high resolution (AWP does not tend to 1), but too small FOO/AVG of low cloud if not using a CFS at all***

Smith and Smith-BL: diagnostic schemes with fixed and diagnosed RHcrit, PC2-BL: prognostic scheme with diagnosed RHcrit.
No shallow cumulus scheme is used

## New CFS with multimodal moisture-temperature PDF

Current diagnostic scheme (Smith 1990) in the MetUM, used in LAM configurations, is based on a symmetric joint moisture-temperature PDF *G(s)*. Cloud fraction and water content are calculated by integrating over the PDF as follows:

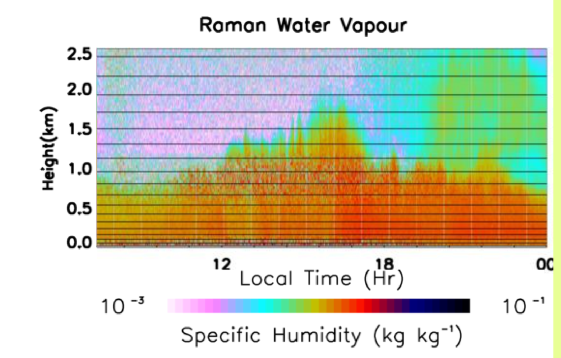
$$C = \int_{s=-Q_c}^{\infty} G(s)ds \qquad \bar{q}_{cl} = \int_{s=-Q_c}^{\infty} (Q_c + s)G(s)ds$$

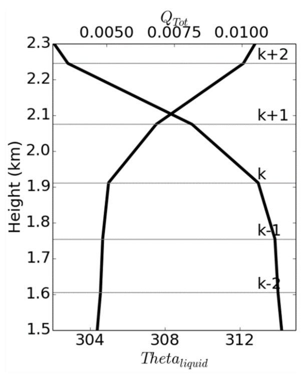
*($Q_c \approx$ grid-mean super-saturation)*

In Smith, PDF variance ($\sigma^2$) is fixed profile, in Smith-BL, $\sigma^2$ is linked to TKE diagnostic from BL scheme via critical relative humidity (Van Weverberg, Boutle et al. 2016 ). Even if $\sigma^2$ scales with resolution, no convergence to all-or-nothing with symmetric PDF.

Cloud scheme changes:

(1) Assume $\sigma_k^2$ caused by penetrations of air form layers above and below, as observed near PBL top*. Require that:



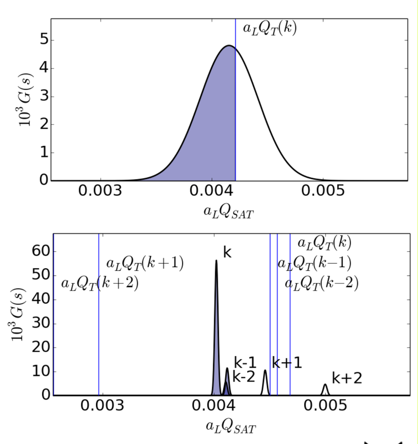

$$\mu_k = A\mu_e + B\sum_{i=k-2}^{k+2}\mu_i \quad (1) \qquad A + 4B = 1$$

$$\sigma_k^2 = A\left((\mu_e - \mu_k)^2 + \sigma_e^2\right) + B\sum_{i=k-2}^{k+2}\left((\mu_i - \mu_k)^2 + \sigma_i^2\right) \quad (2)$$

where $\mu$ is mean of joint moisture-temperature PDF, $\sigma_k^2$ is variance from BL scheme and $\sigma_e^2$ and $\sigma_i^2$ are small 'background' variances, as obtained from aircraft measurements.

Solve equation set analytically for weights A and B. If no real solution, set A to1/3 and solve equation set for $\sigma_e^2$ and $\sigma_i^2$.

(2) Remove assumption that $CF_l$-$q_{cl}$ relation for liquid also holds for ice. $q_{ci}$ is produced by microphysics, accounting for super-saturation. If ice is formed, integrate over PDF as for the liquid phase. If sub-saturated, use ice cloud fraction from layer above (falling ice).

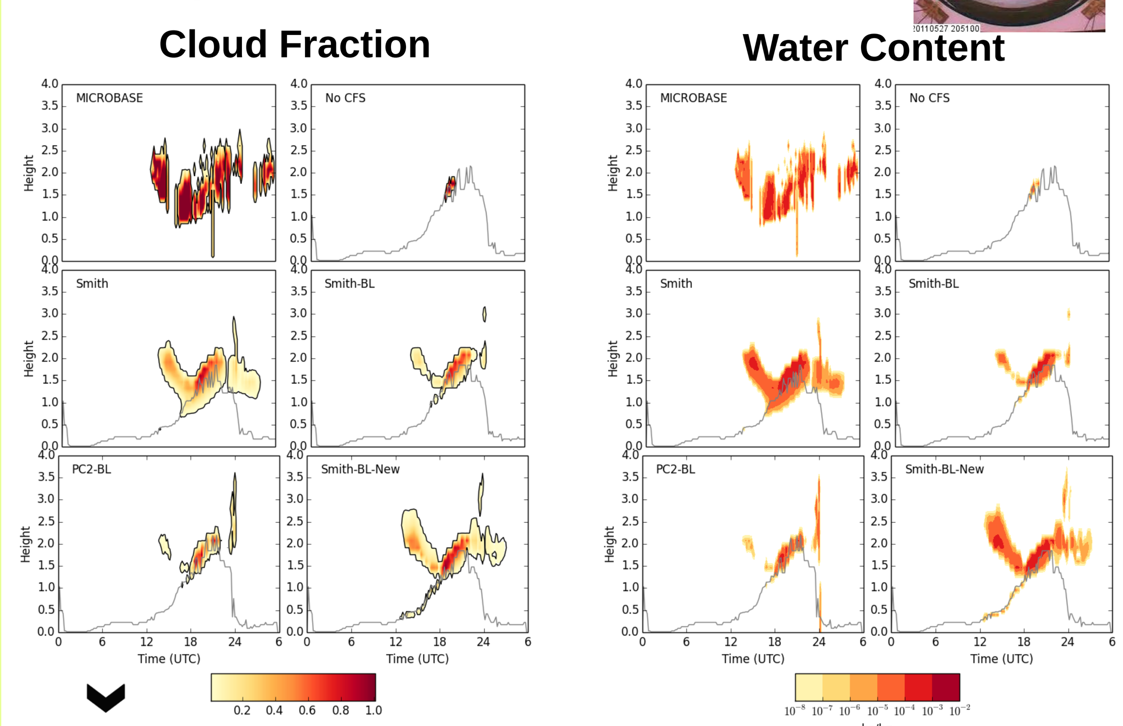



***Original (top) and new (bottom) PDFs for identical $\mu$ and $\sigma^2$. Cloud Fraction of 0.54 and 0.81 respectively***

* note that we do not assume mixing or transport, these are dealt with by the BL scheme

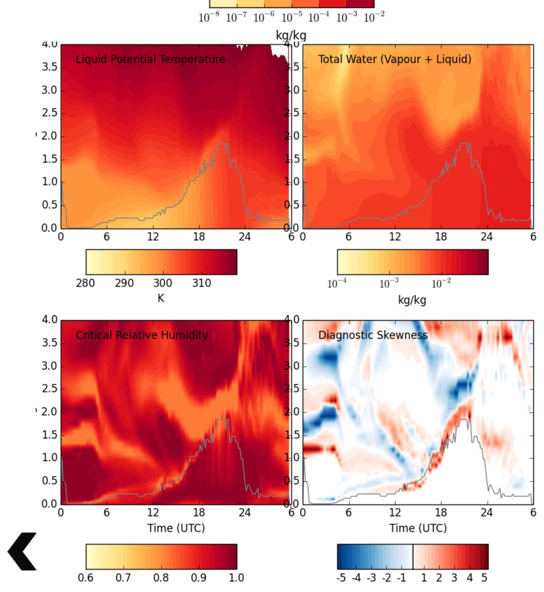
## Shallow Cumulus Case

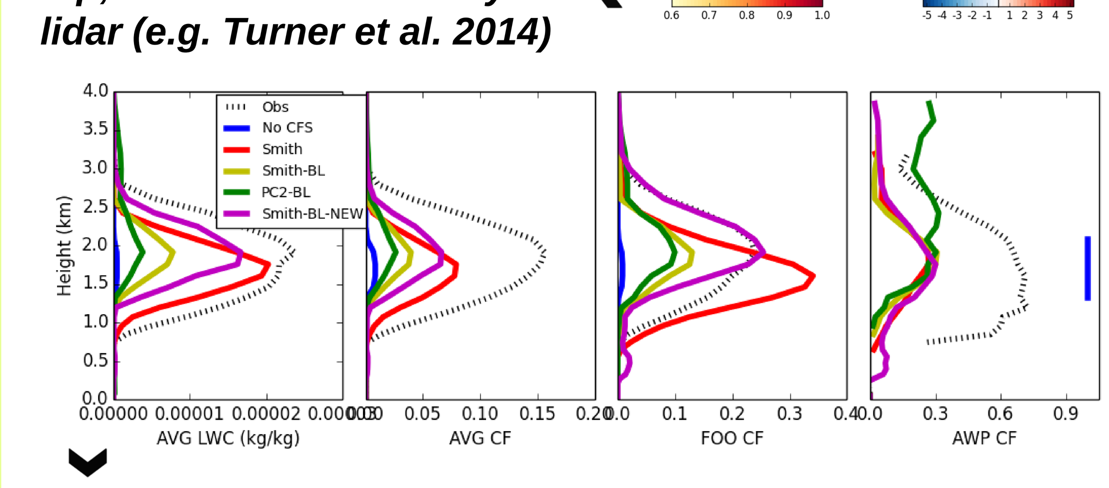
27 May 2011




***No CFS largely underestimates cloud. CFS needed and Smith-BL-New increased CF near PBL top, in better agreement with obs.***

***New CFS gets large cloud cover even when variance is large (RHcrit is small). Scheme implicitly simulates positive skewness near PBL top, as often observed by lidar (e.g. Turner et al 2014)***

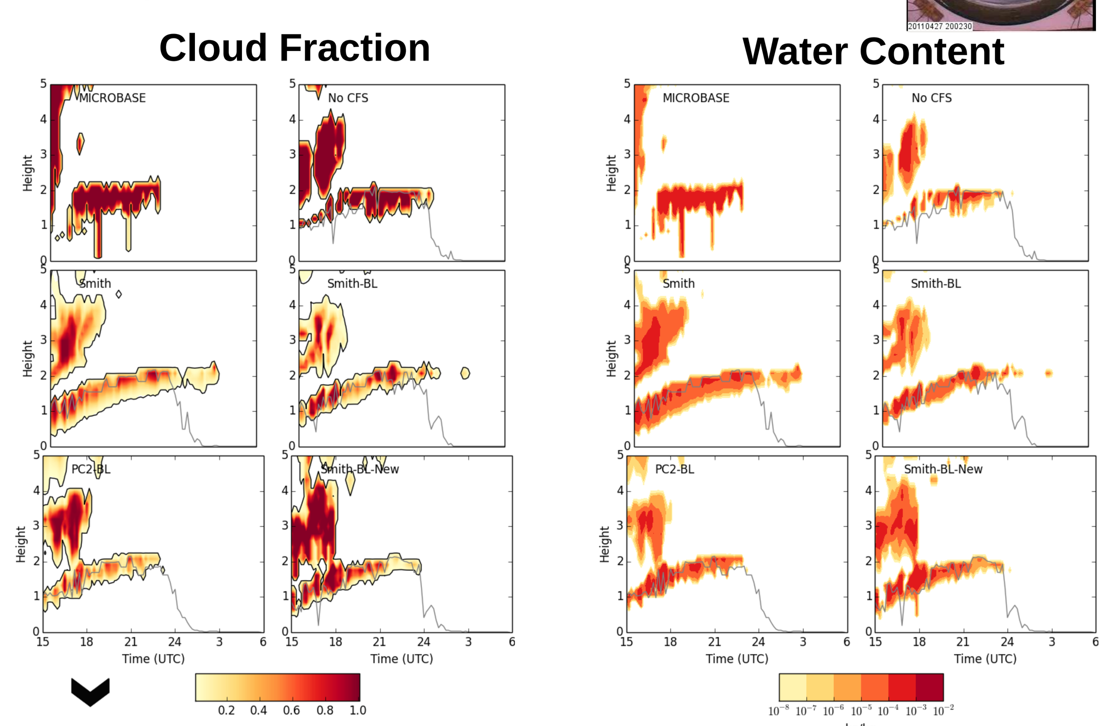



***Improved LWC, AVG and FOO of Smith-BL-New compared to Smith-BL. No CFS underestimates cloud in this case.***

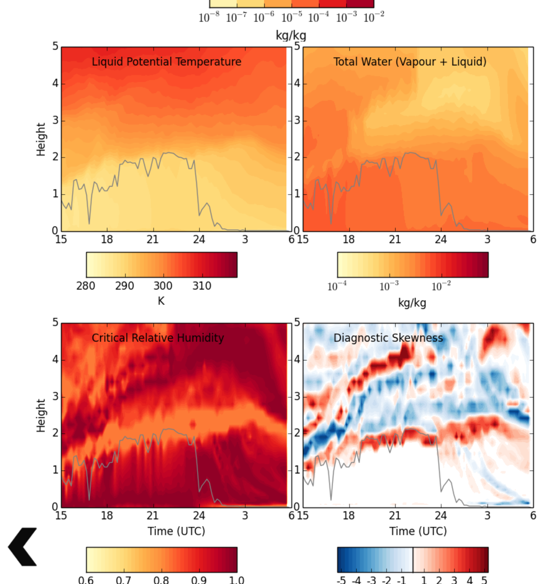
## Stratocumulus Case

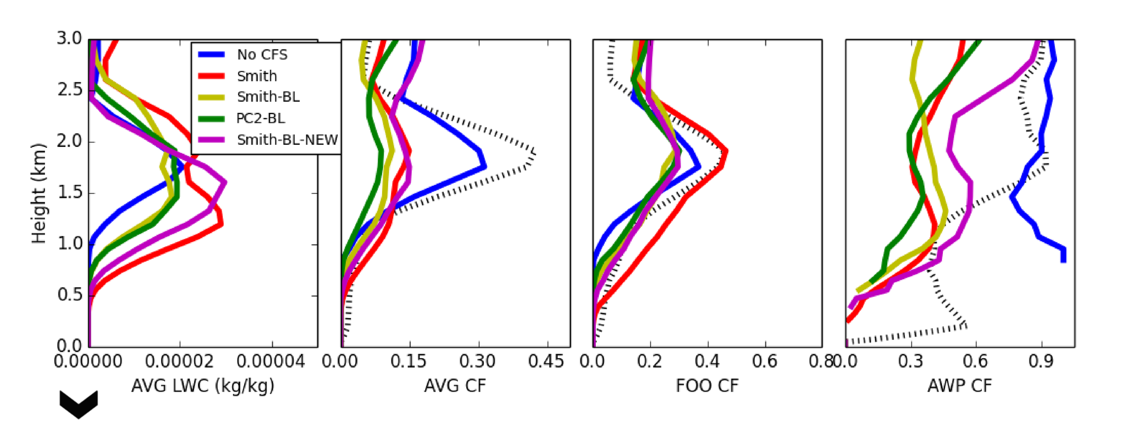
27 April 2011




***Simulation without CFS appears better than with CFS in this case, although Smith-BL-New closer to full cloud cover than other CFS.***

***Similar to shallow cumulus case, Smith-BL-New gets fairly full cloud cover, even when variance is large. Large implicit positive skewness near top of PBL***

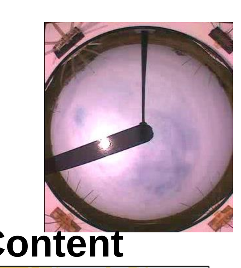


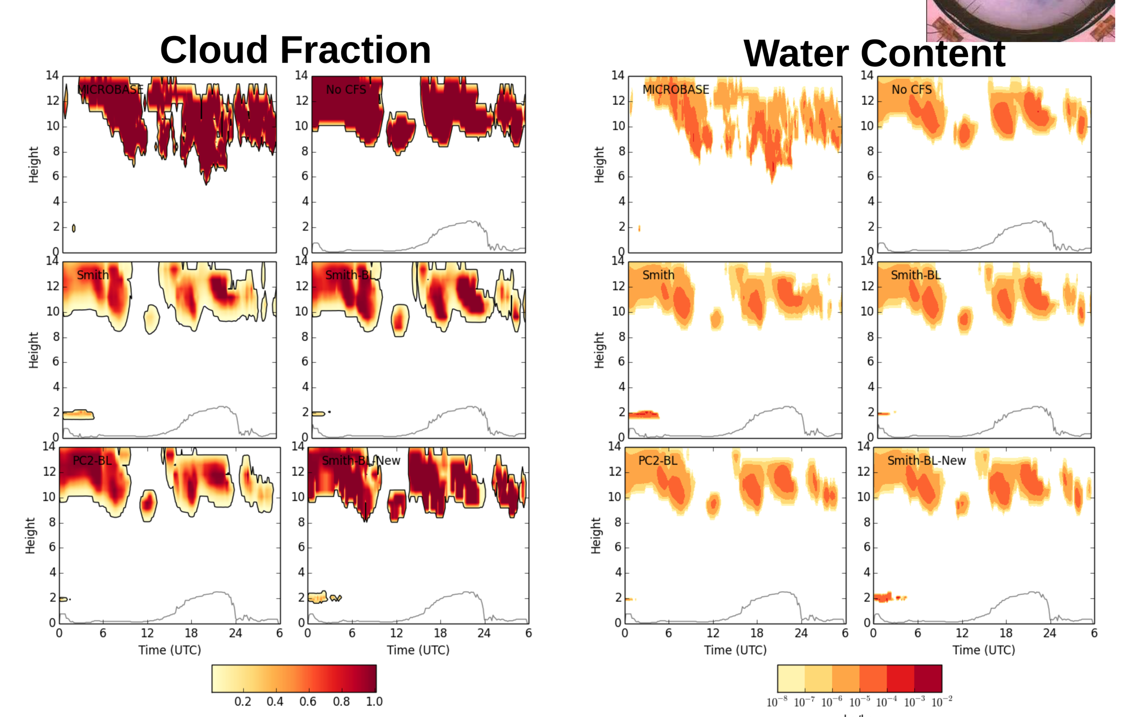



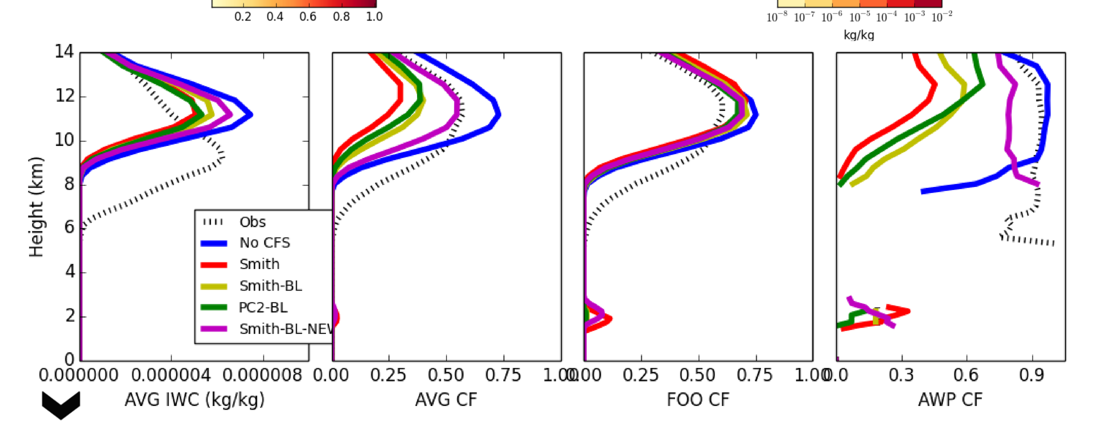

***No CFS appears better in this case, but Smith-BL-New leads to larger AWP compared to other CFS***

## High Cloud Case

2 June 2011






***Smith-BL-New appears to outperform other CFS in terms of AVG cloud fraction and AWP***

## Conclusions

- **Even at 1 km grid spacing, a sub-grid cloud scheme is beneficial, but current schemes struggle to converge to all-or-nothing behaviour.**
- **New diagnostic scheme combines PDFs from other layers, assuming variance caused by undulating PBL top. Can get to fuller cloud cover in large variance and implicitly simulates skewness near PBL top, similar to observations. Also proposed new way of calculating ice cloud cover.**
- **This is work in progress: Methodology will be further fine-tuned (e.g. making number of layers function of turbulent length scale), new simulations for full MC3E period and cases of stable stratocumulus over the North Sea in the UK under way.**

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ASR Atmospheric System Research Met Office

Observational data presented here are from the Microbase-KA VAP and were gratefully obtained from Karen Johnson (Brookhaven National Laboratory)

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