The impact of parametrized convection on cloud feedback.

Mark Webb, Adrian Lock (Met Office)

Thanks also to Chris Bretherton (UW), Sandrine Bony (IPSL),Jason Cole (CCCma), Abderrahmane Idelkadi (IPSL), Sarah Kang (UNIST), Tsuyoshi Koshiro (MRI), Hideaki Kawai (MRI), Tomoo Ogura (NIES), Romain Roehrig (CNRM), Yechul Shin (UNIST), Thorsten Mauritsen (MPI), Steve Sherwood (UNSW), Jessica Vial (IPSL), Masahiro Watanabe (AORI), Matthew Woelfle (UW), Ming Zhao (GFDL).

CFMIP Meeting, Monterey, June 2015

Selected Process On/Off Klima Intercomparison Experiment (SPOOKIE)

Aims

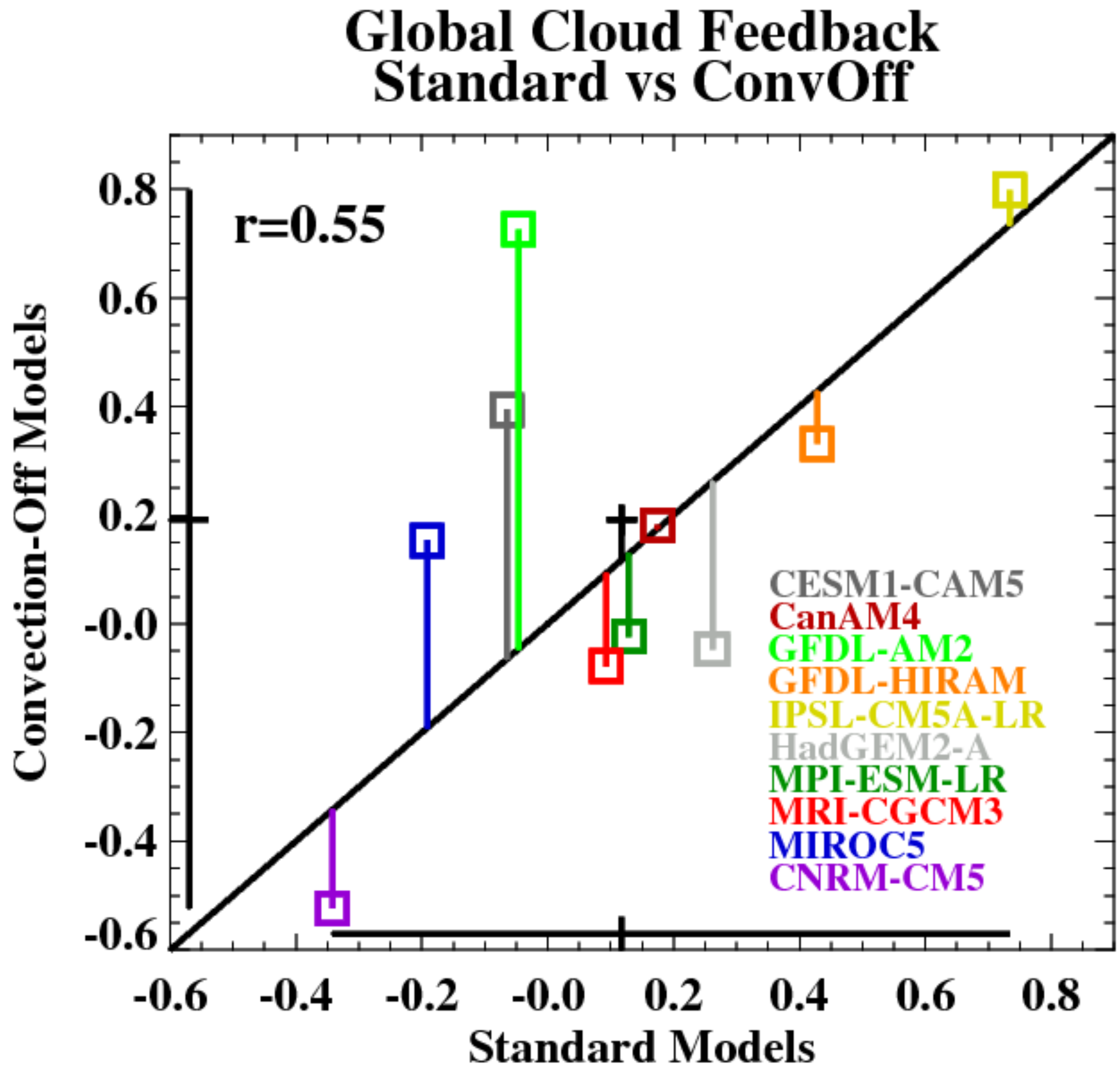
- Establish the relative contributions of different areas of model physics to inter-model spread in cloud feedbacks

Approach

- Repeat CFMIP-2 AMIP/AMIP Uniform +4K SST perturbation experiments
- Switch off or simplify different model schemes in turn

Pilot Experiments

- Start by switching off convective parametrization



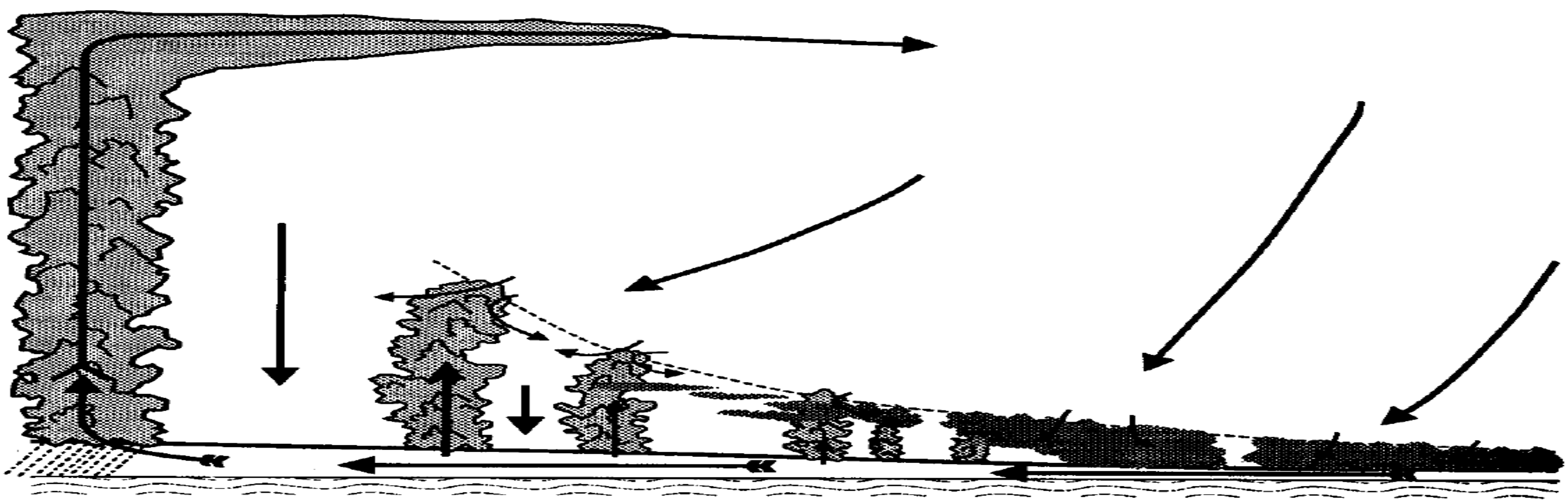
The Cloud Radiative Effect (CRE) is the difference in the net downward radiation at the top of the atmosphere with and without clouds.

Here we diagnose the cloud feedback as the change in net CRE between amip and amip4K divided by the change in global surface temperature.

This includes the climatological ‘cloud masking’ effect on the non-cloud feedbacks.

Organisation of tropical cloud regimes

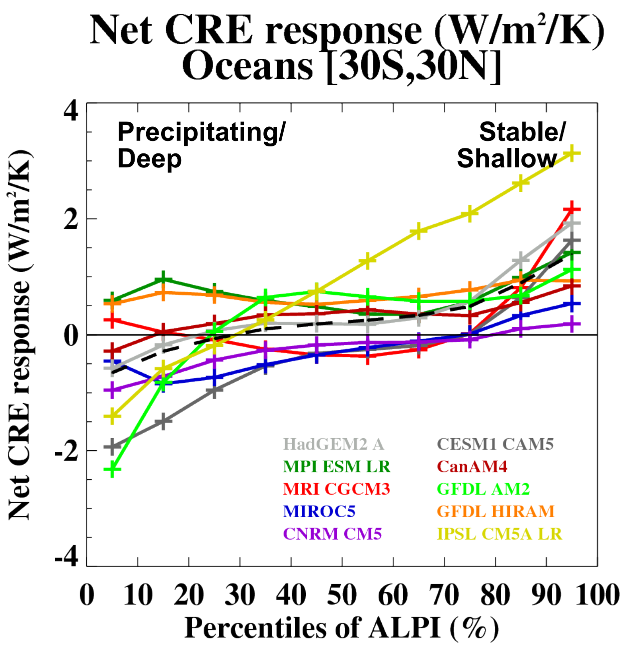
Deep Convection **Trade Cumulus** **Stratocumulus**



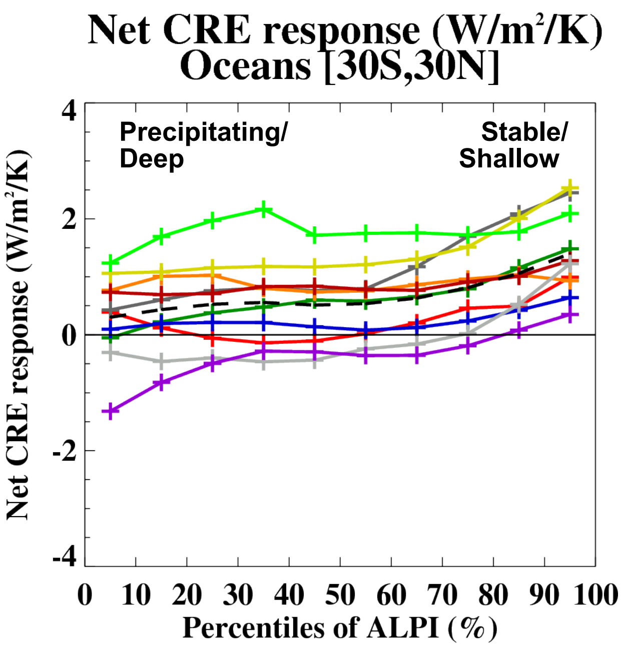
Schematic from Emanuel (1994)

amip4K Cloud Feedbacks over 30ºN/S Oceans

Standard



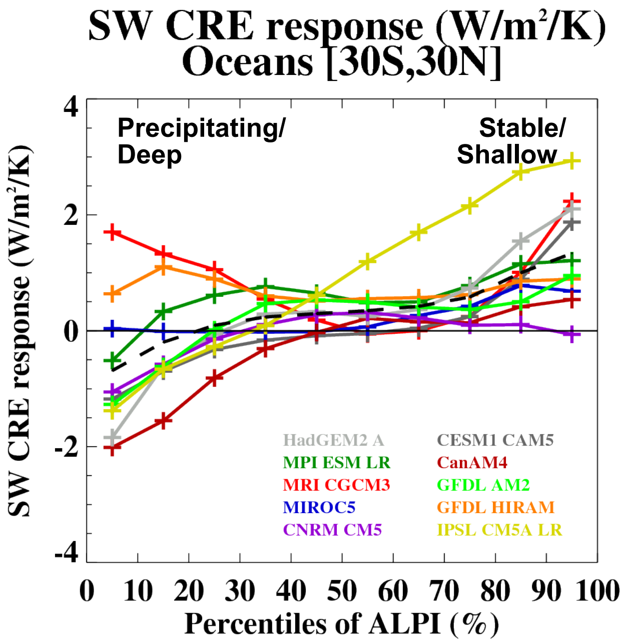
ConvOff



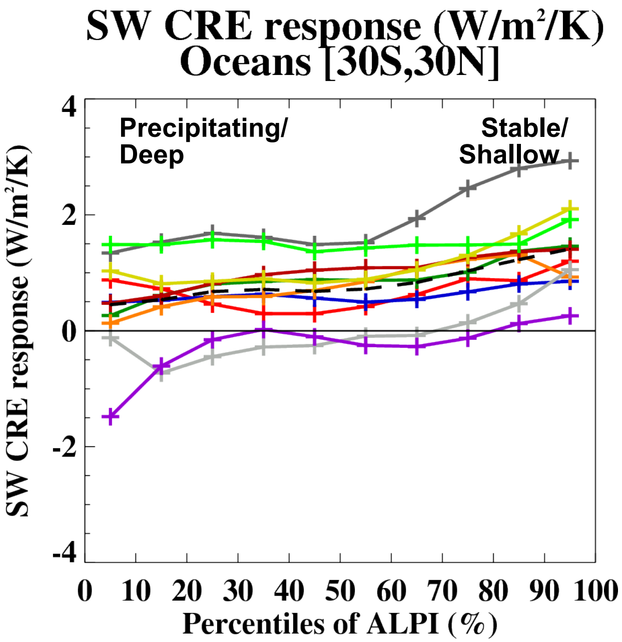
We sort cloud regimes in the tropics using a composite index based on precipitation rate and Lower Tropospheric Stablity (LTS). We call this the Angular LTS/Precipitation Index (ALPI).

amip4K Cloud Feedbacks over 30^{O}N/S Oceans

Standard

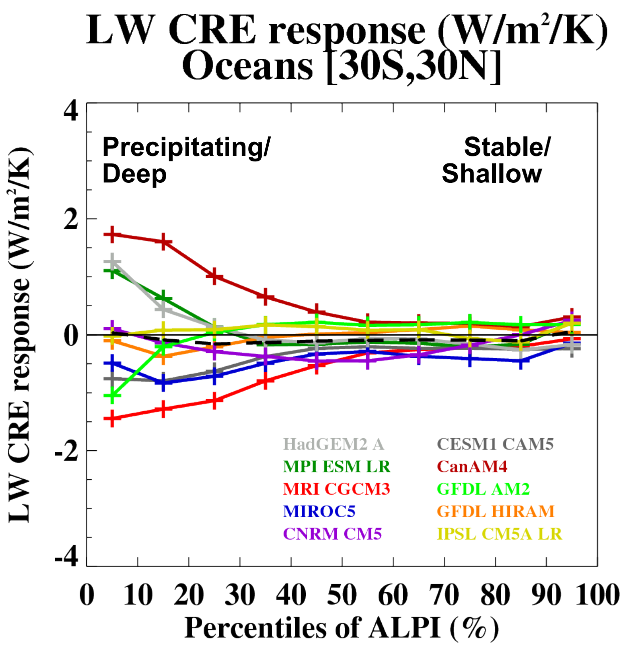


ConvOff

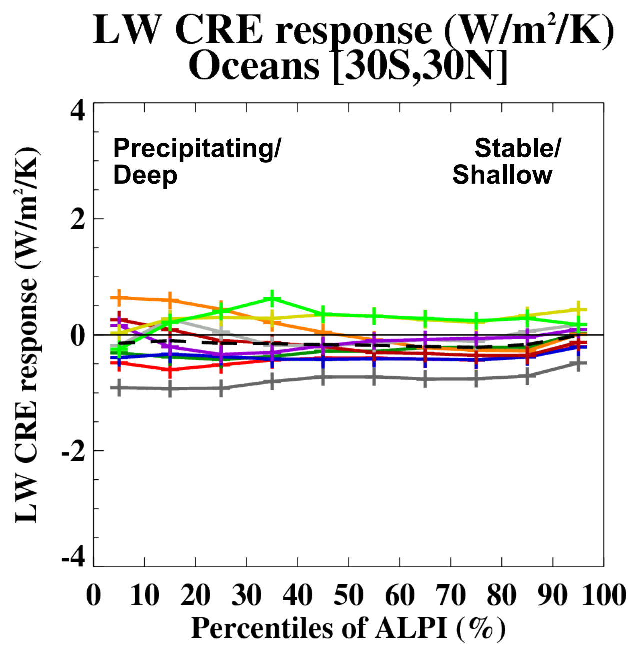


amip4K Cloud Feedbacks over 30^{O}N/S Oceans

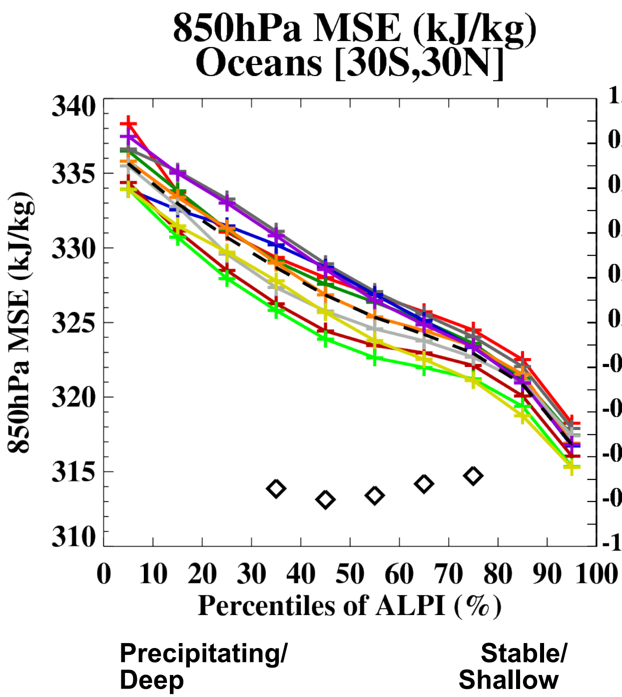
Standard



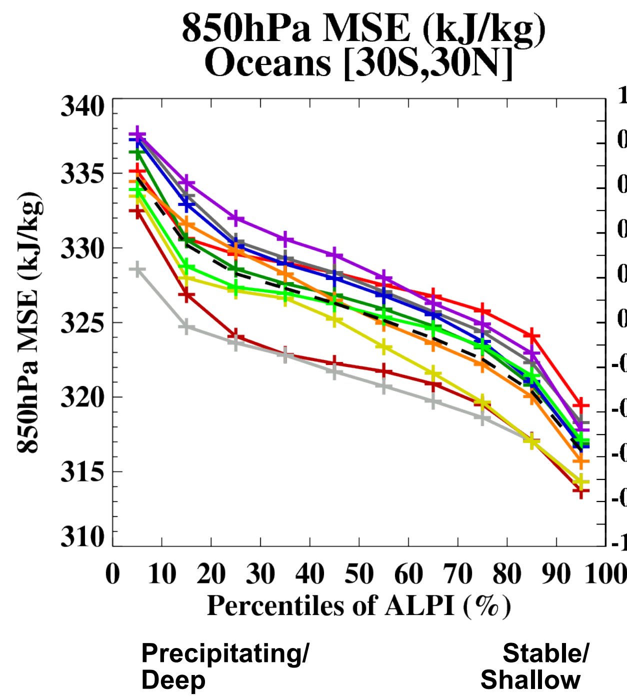
ConvOff



Standard Models



ConvOff Models



Black diamonds mark significant correlations with the net cloud feedbacks in same regime

Grey squares mark significant correlations with the net cloud feedback area averaged over tropical oceans

Moist Static Energy (MSE) is a measure of the energy in a parcel of air, including sensible heat due to temperature, latent heat due to water vapour and potential energy due to height.

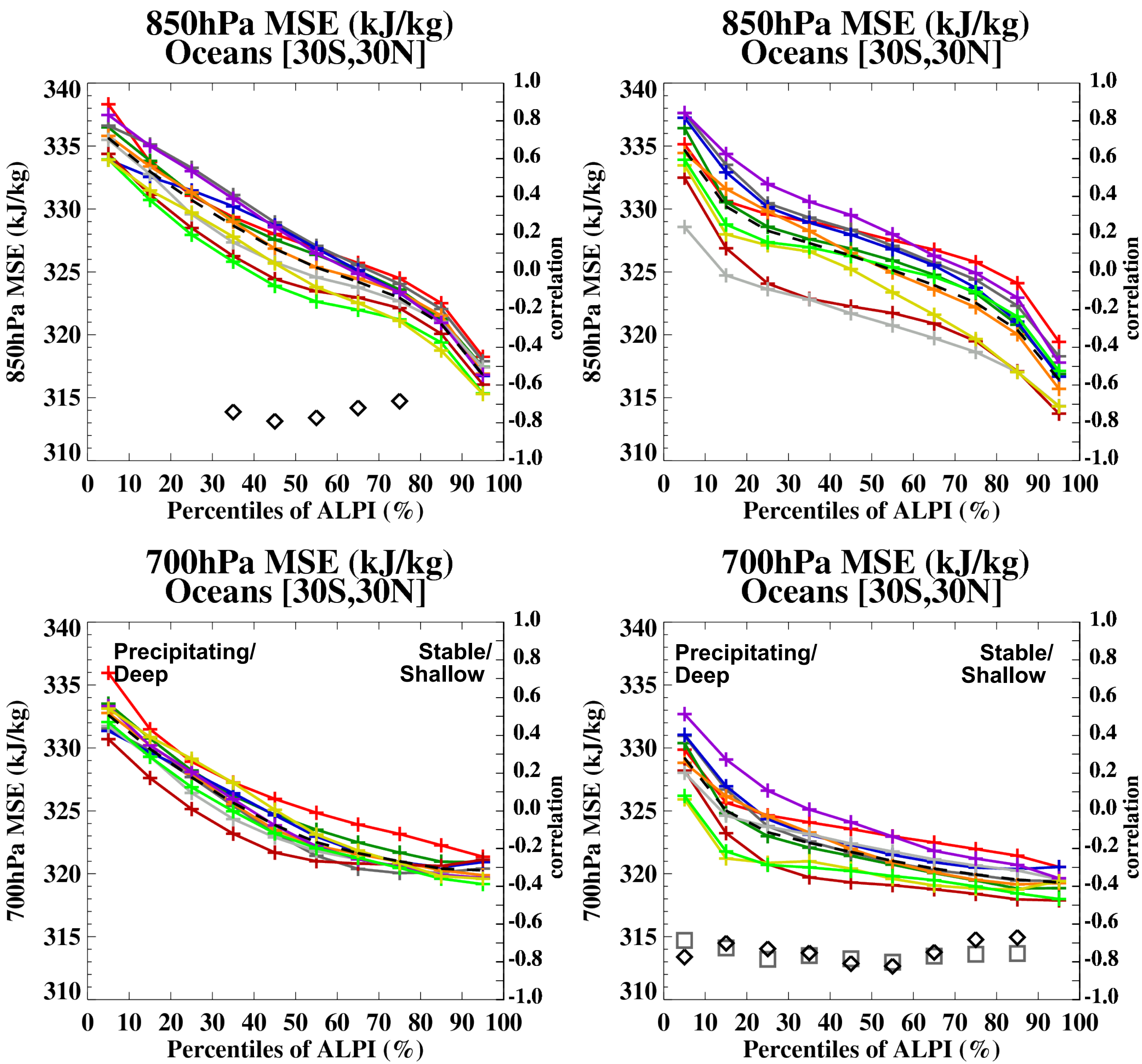
$$MSE = C_P T + L_v q + gz$$

C_P is the specific heat of air at constant pressure
L_v is the latent heat of vaporization
g is the acceleration due to gravity

T is temperature
q is the specific humidity
z is the height above the surface

Standard Models

ConvOff Models



Black diamonds mark significant correlations with the net cloud feedbacks in same regime

Grey squares mark significant correlations with the net cloud feedback area averaged over tropical oceans

Why might models with less MSE near the top of the PBL have more positive cloud feedbacks?

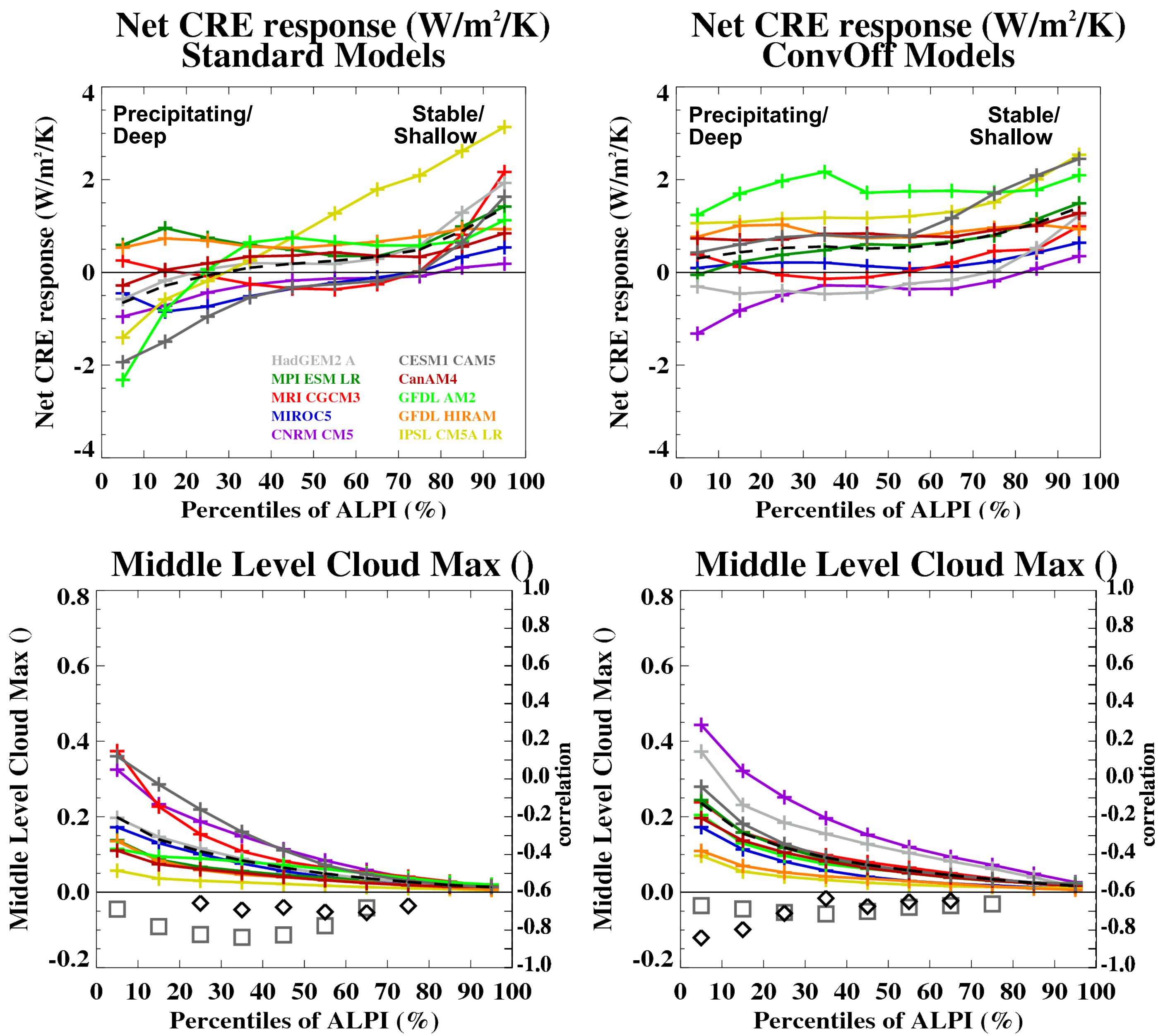
Met Office

- Sherwood et al. 2014 and Zhao 2014 argue that precipitation efficiency plays an important role in cloud feedback.
- Sherwood et al. 2014 defines the bulk precipitation efficiency in terms of the upward transport of water vapour from the boundary layer to the free troposphere required to maintain a given surface precipitation rate.
- In GCMs such transports are due to 'lower tropospheric mixing' by small scale processes such as parametrized convection or turbulence and by large scale mixing associated with the resolved large scale circulation.
- Sherwood et al. 2014 argue that models with stronger lower tropospheric mixing will have a stronger drying of the boundary layer, and that this drying effect will strengthen more in the warming climate, resulting in stronger low cloud reductions and more positive cloud feedbacks.
- Reduced MSE near the top of the PBL in higher sensitivity models could then be a consequence of stronger lower-tropospheric mixing in accordance with the arguments of Sherwood et al.

What processes other than parametrized convection regulate lower tropospheric mixing?

- Inter-model differences in parametrized convection and its precipitation efficiency cannot explain the overall range in cloud feedbacks in the models examined here.
- Zhao, 2014 defines precipitation efficiently slightly differently to Sherwood et al. and makes a distinction between precipitation efficiency associated with convective schemes and large scale cloud/precipitation schemes.
- Might inter-model spread in lower tropospheric mixing and cloud feedback instead be explained by inter-model differences in the precipitation efficiency associated with the large scale cloud and precipitation schemes?

Standard   ConvOff



Black diamonds mark significant correlations with the net cloud feedbacks in same regime

Grey squares mark significant correlations with the net cloud feedback area averaged over tropical oceans

Met Office

Why might less present-day mid-level cloud lead to more positive low cloud feedback?

- In radiative-convective equilibrium, convection adjusts to provide enough heating to balance longwave radiative cooling in the free troposphere.
- Models which easily form precipitating clouds in the mid troposphere will rain out efficiently to the surface.
- Models which form mid level clouds less easily will need to condense higher up to provide the required latent heat release in the free troposphere.
- Precipitation from higher clouds has further to fall and more time to evaporate, offsetting latent heating and requiring a stronger upward transport of water vapour to maintain the surface precipitation rate.
- Hence having less mid level cloud in models might result in stronger lower tropospheric mixing, an enhanced drying of the PBL in the warmer climate, and more strongly positive cloud feedbacks.

Testing our ideas – future experiments.

Met Office

- The large scale precipitation efficiency in models could be reduced by modifying the cloud microphysics to make it harder to rain from mid-level clouds.
- Alternatively, cloud condensation at mid levels could be suppressed by re-evaporating cloud water.
- Reducing ice fall speeds would also reduce precipitation efficiency.
- If the ideas outlined above are correct, then these experiments would be expected to reduce precipitation efficiency, increase upward transports of water vapour and boundary layer drying, reduce MSE near the top of the boundary layer and strengthen positive low level cloud feedbacks.

Summary

- ConvOff experiments reproduce positive subtropical cloud feedback.
- They show strong convergence in tropical deep convective longwave cloud feedbacks but increased spread in net cloud feedback in the trades.
- Differences in parametrized convection can have a substantial impact on global cloud feedback in some models, but do not explain the overall range.
- Higher sensitivity models in both standard and ConvOff ensembles have:
  - Less moist static energy near boundary layer top
  - Less mid-level cloud in trades / deep convection regimes
- We have developed some ideas which may explain these results and will test them in future process suppression experiments.
- Such experiments could form the basis for SPOOKIE phase 2.