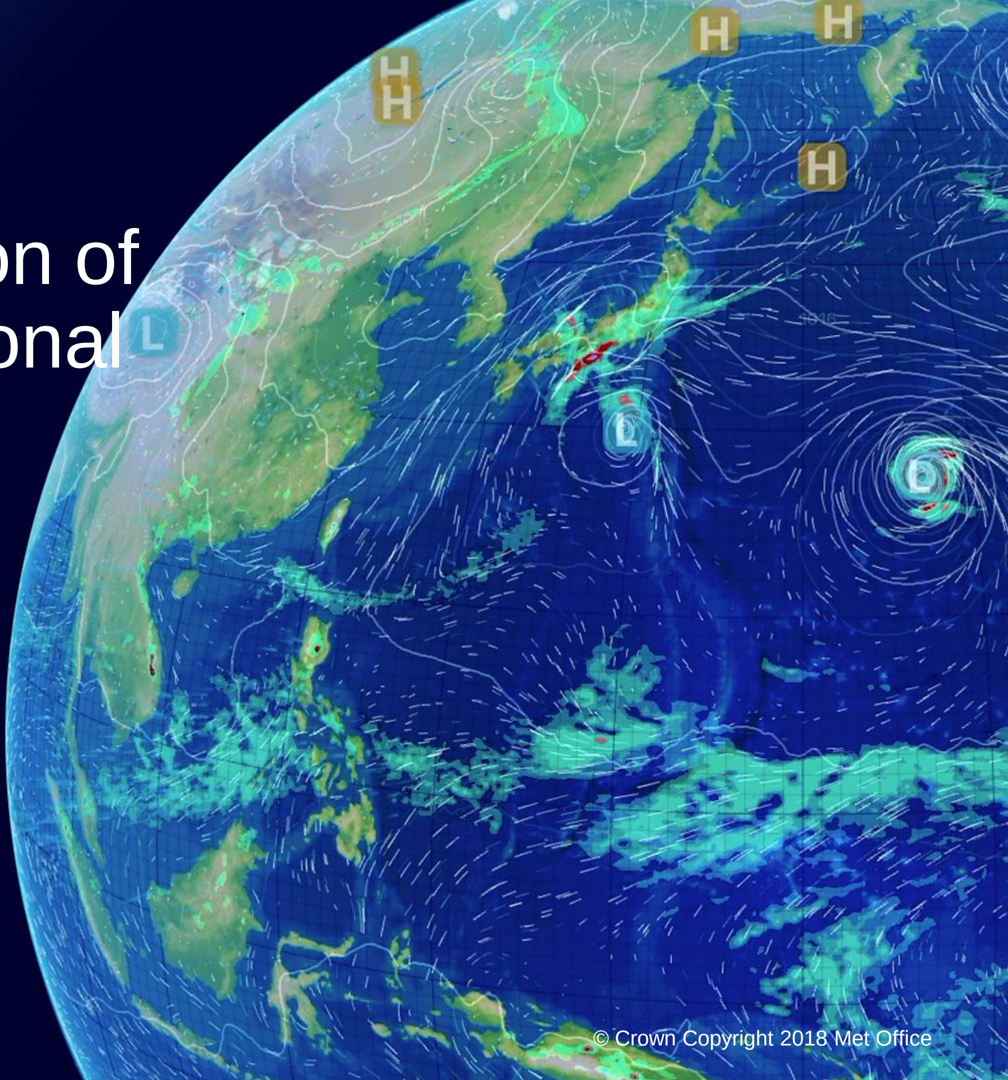
Met Office

Introducing an Improved Multilayer Parametrization of Lying Snow into Operational Weather and Climate Modelling



GABLS4 Workshop, Toulouse, Sept. 2018

J. M. Edwards

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Motivation

- The real SBL must be understood from a coupled perspective
- We need to understand the role of the surface as well as the atmosphere
- An example of trying to get a new physical scheme into operational use
  - With some insight from GABLS4

Background

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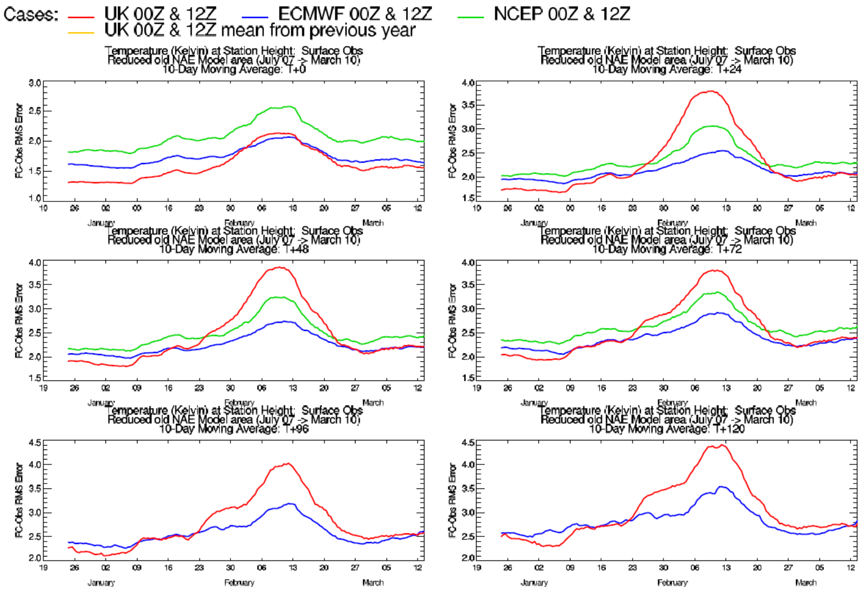
- Lying snow is often treated simplistically in models
- UM has long had a 0-layer scheme
  - No separate thermal store for snow
  - No representation of snow physics
- Poor representation of insulating effect of snow pack
  - Sluggish response to rapidly falling air temperature
  - Cold biases over seasonal timescales
  - Excessive permafrost in ESM



UM shows pronounced temperature errors over Europe in early 2012

Relevant Snow Physics

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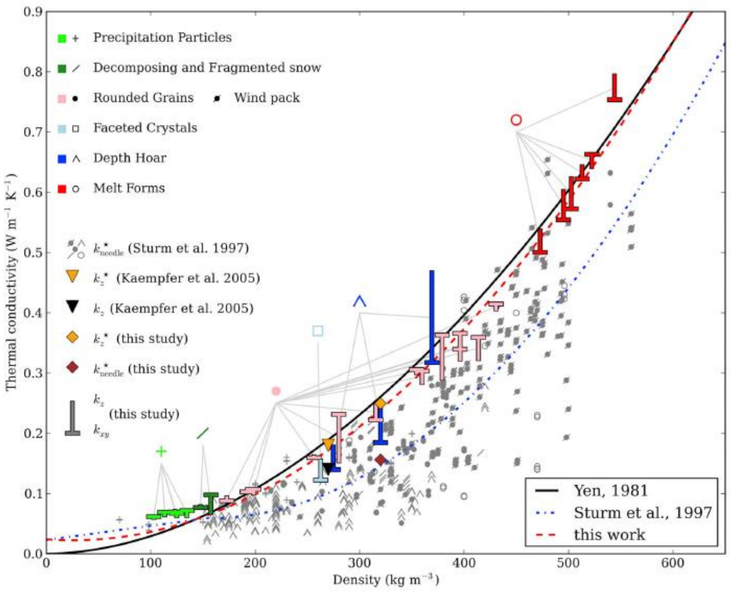
- Snow affects surface fluxes through
  - Surface Roughness
  - Thermal conductivity
  - Albedo

- Thermal conductivity is strong function of temperature
  - (Conduction through air in the snow pack matters)

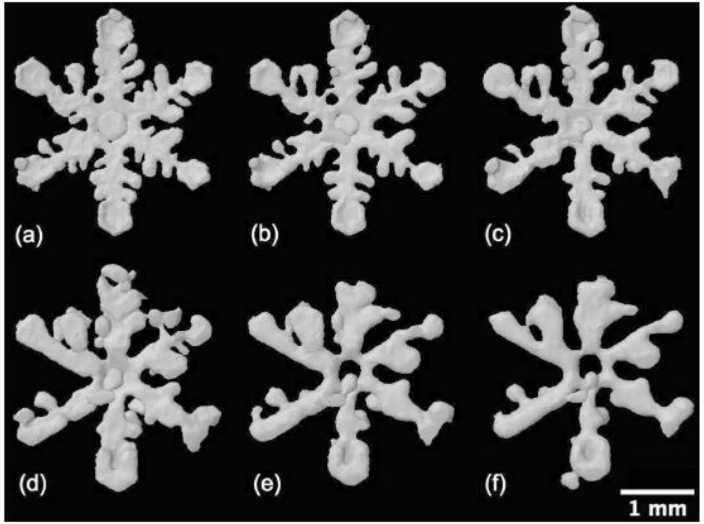
- Albedo depends on grain size and impurities



Calonne et al. (2011), GRL, 38, L23501

Relevant Processes

- Density of fresh snow
- Metamorphism
  - Equitemperature
  - Temperature gradient
- Mechanical compaction
- Growth of grains (albedo)
- Impurities (albedo)

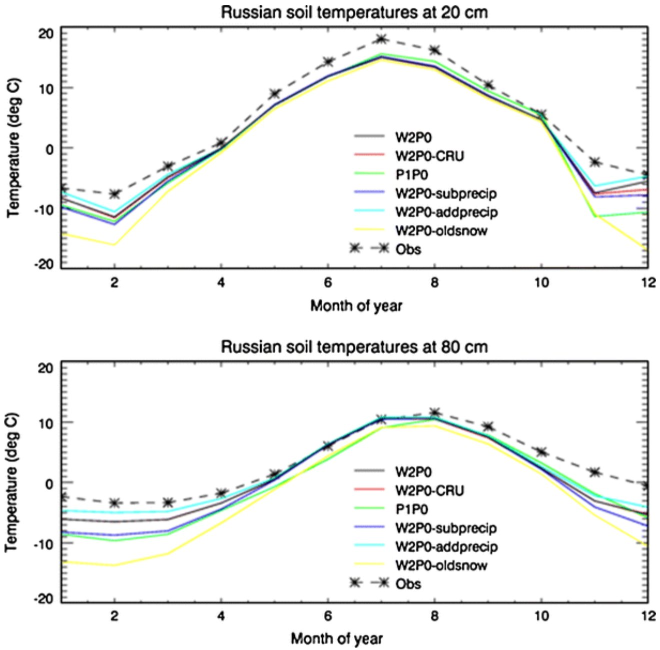


Example of ET Metamophism: Chen & Baker (2010), JGR, 115, D21114

Multilayer Scheme

- Developed by Richard Essery at Edinburgh University
- Explicit representation of the snow pack
- Layers added or removed subject to a specified maximum
  - 3 layers are generally sufficient for application in NWP
  - Default thicknesses 0.1, 0.2m + unconstrained depth of lower layer
  - Not a stratigraphic model
- Mechanical compaction of snow
  - Regridding of snow pack after snowfall and compaction
- Liquid and frozen water stores
- Growth of grains with time
- Canopy interception

- Poor insulation of zero-layer scheme is significant problem in simulation of permafrost
  - Extent significantly overestimated
- Standalone simulations (Burke et al. 2013) show better insulation with new scheme and more realistic extents



First tests in UM (April 2012)

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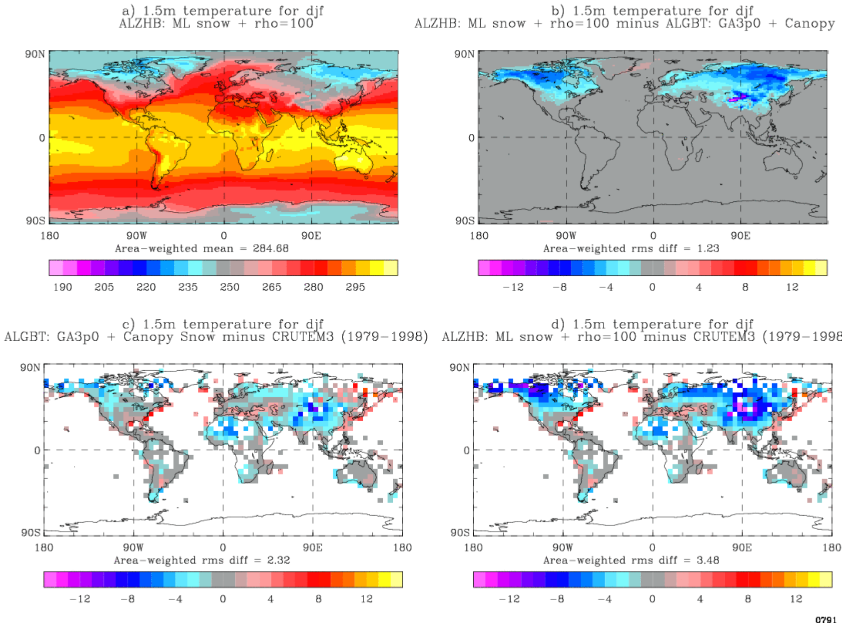
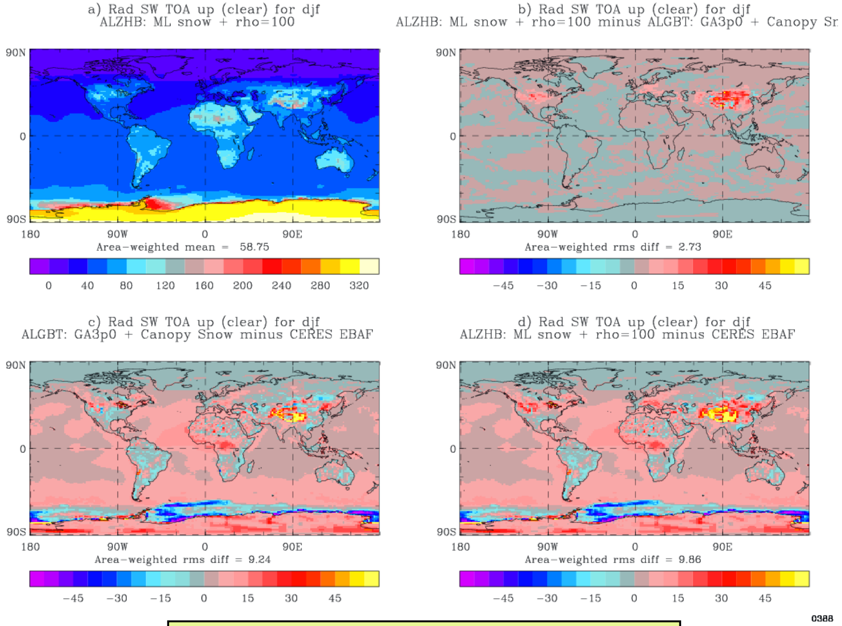


T1.5 much worse in DJF



Excessive reflection over mid-latitude land

Enhancements

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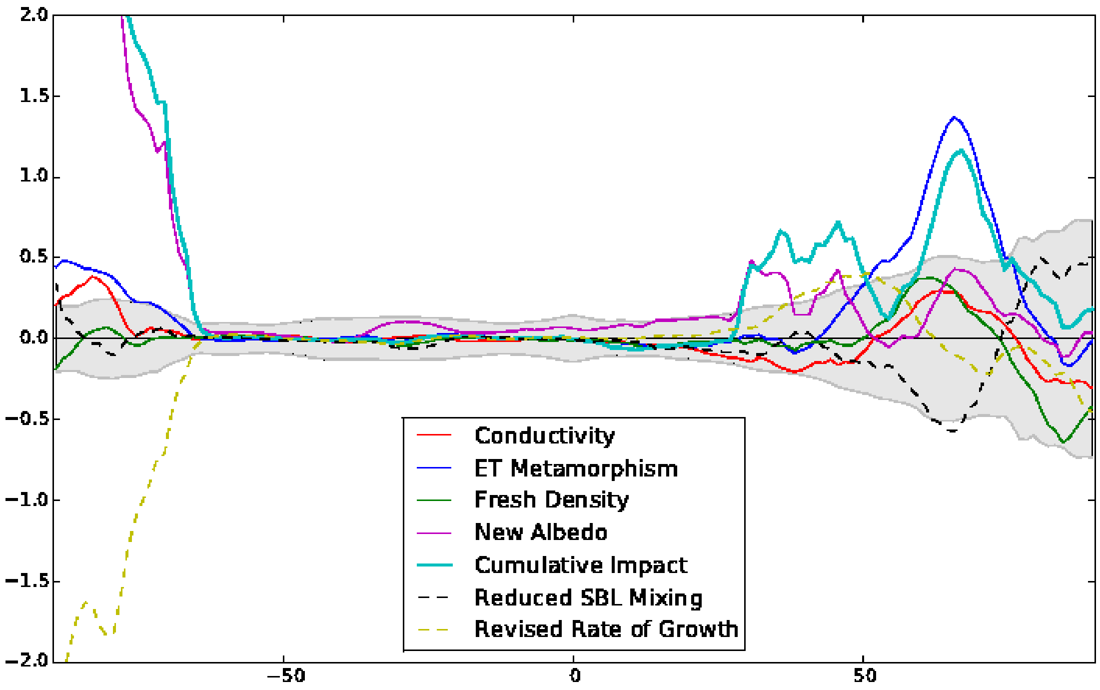
- When coupled to an atmospheric model, the surface temperature is very sensitive to processes near the snow surface
- Modifications:
  - Replace thermal conductivity from Yen (1981) by Calonne et al. (2013)
    - Conduction through the air in fresh snow matters
  - Introduce ET metamorphism (densification of fresh snow)
    - TG metamorphism not currently included
  - Aim for thinner top layer (0.04, 0.12 m and the rest)
  - Unloading of snow from plant canopies made dependent on wind speed
  - Infiltration of rain into snowpack
  - Revised albedo scheme

Sensitivity of T1.5m to some of the changes



Testing for operational use

- Standard tests for any change:
  - 20-year AMIP climate integration
  - Set of 5-day summer and winter global NWP forecasts
- Acceptable changes are packaged and tested together in NWP & climate tests and subsequently in summer and winter trials with data assimilation
- Final tuning of package eg. for TOA radiation budget
- Consolidation into defined configuration
- Operational implementation – aim at one operational upgrade to physics every year

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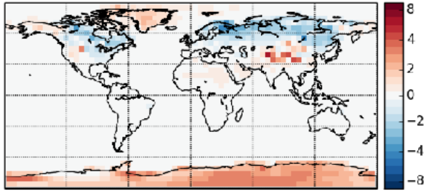
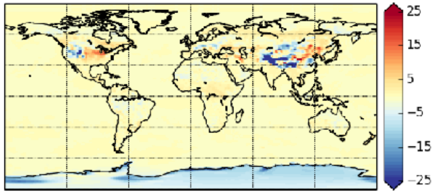
Impact in climate simulations (DJF)

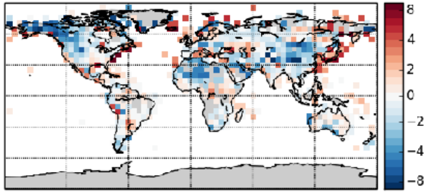
Difference in T1.5m (EXP-CTL)

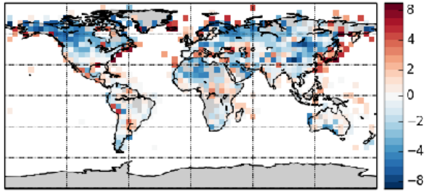




Difference Clear-sky Reflected SW

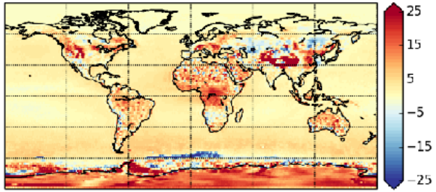
Error in T1.5m (CTL – CRUTEM3)

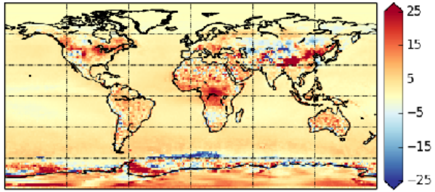




Error in T1.5m (EXP – CRUTEM3)

Error in Clear RSW (CTL – CERES_EBAF)





Error in Clear RSW (EXP – CERES_EBAF)

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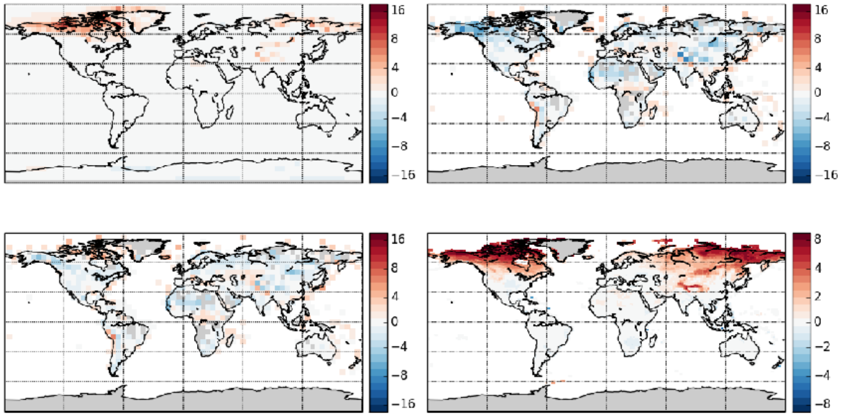
Impact in climate simulations (MAM)

Difference in T1.5m
(EXP-CTL)

Error in T1.5m
(CTL – CRUTEM3)



Error in T1.5m
(EXP – CRUTEM3)

Difference in annual mean soil temperature at 2m
(EXP – CTL)

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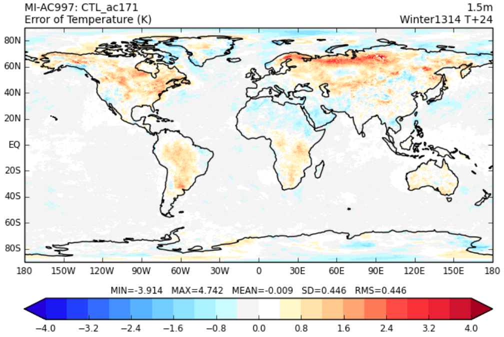
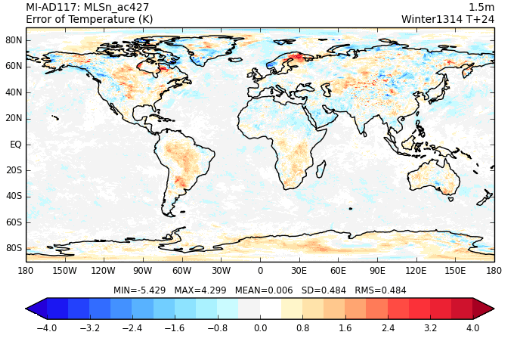
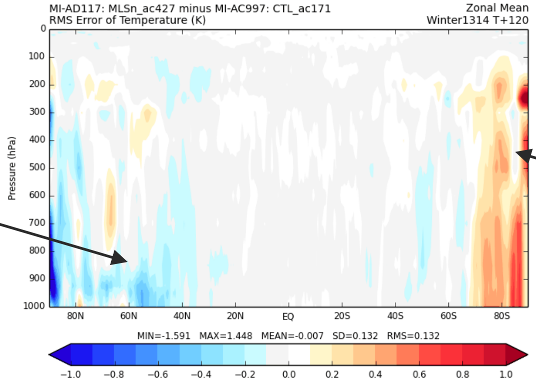
Impact in NWP Case Studies





Short-range warm bias in T1.5m in NH reduced

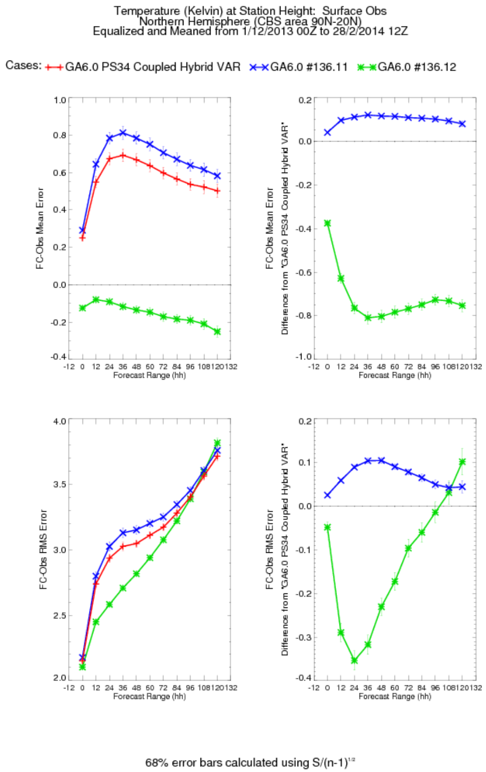


Reduced RMS error in zonal mean temperature at T+120 in NH

Increased RMS error at T+120 over Antarctica

Interaction with data assimilation

- Snow pack evolves on the timescale of days or weeks
  - Full trial with DA through winter is required
  - Even at lower resolution (~1 degree) took about 4 months on last supercomputer
- Significant reduction in RMS error over first couple of days
  - More responsive snow pack
- Longer term errors increased
  - Also effect of more responsive snow pack



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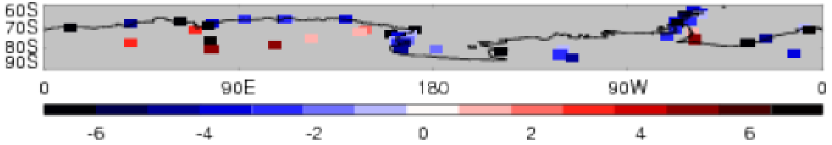
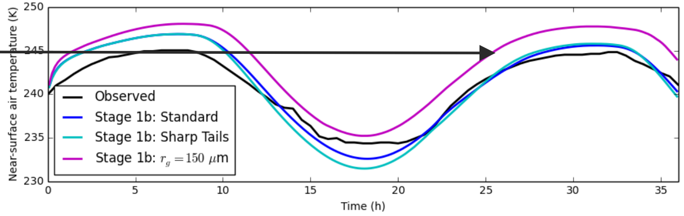
Some Guidance from GABLS4

- Version just described has been implemented in CMIP6 runs
- Further investigation of warm bias was needed for NWP applications
- Synoptic observations suggest warm bias over Antarctic Plateau
- Simulation of Stage 1b in GABLS4 shows persistent warm bias

00 UTC 27/12/2013, T+48





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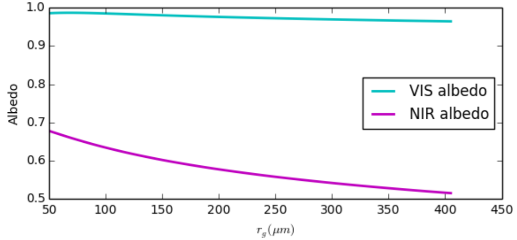
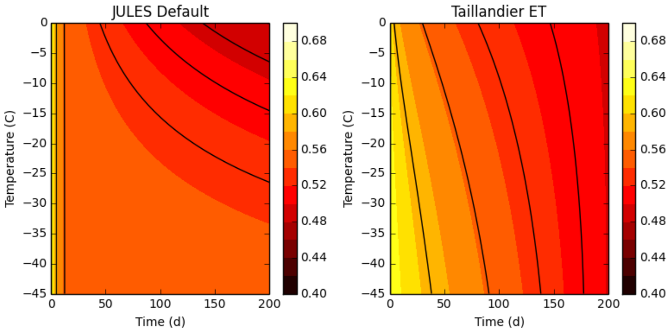
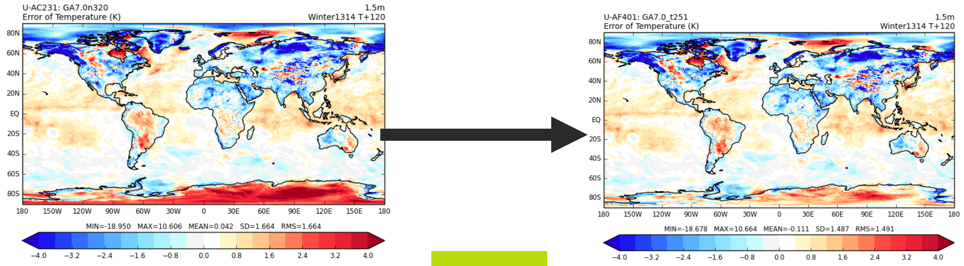
- For GABLS4 grain size was set up 69 μm to give mean albedo of 0.81
- Original parametrization of grain growth (Marshall 1989) gives rapid increase up to 150 μm over Antarctica and very slow growth thereafter
  - Clear-sky RSW agreed well with CERES-EBAF
- Gallet et al. (2011) suggest grain size closer to 80 μm from measurements
- Replaced parametrization of grain growth with Taillandier's scheme for growth of grains under ET metamorphism
- Relayer grain size using $1/r_g$ to conserve SSA



NIR Albedo





Final Testing for Global Forecasting (Summer 2018)

Final Package

- Surface and changes to processing of observations
  - Multilayer Snow + associated changes
  - Form drag for sea ice based on Lupkes & Gryanik (2015), Elvidge et al. (2016)
  - Upgrade surface roughness over sea to latest COARE algorithm
  - Changes to surface albedo (of vegetation) based on VIS/NIR GlobAlbedo data
  - Recalculate background errors for DA every hour instead of 3 hours
- Running as a parallel suite since May – clear benefit in scores
- Planned to go live on 18/9/2018