An Overview of Current Understanding of Snow Albedo Feedback

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dependence of
planetary albedo on
surface albedo

change in surface
albedo with SAT

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In the AR4 models, the SAF feedback parameter exhibits approximately a factor of three spread.

I. Relevance of Snow Albedo Feedback

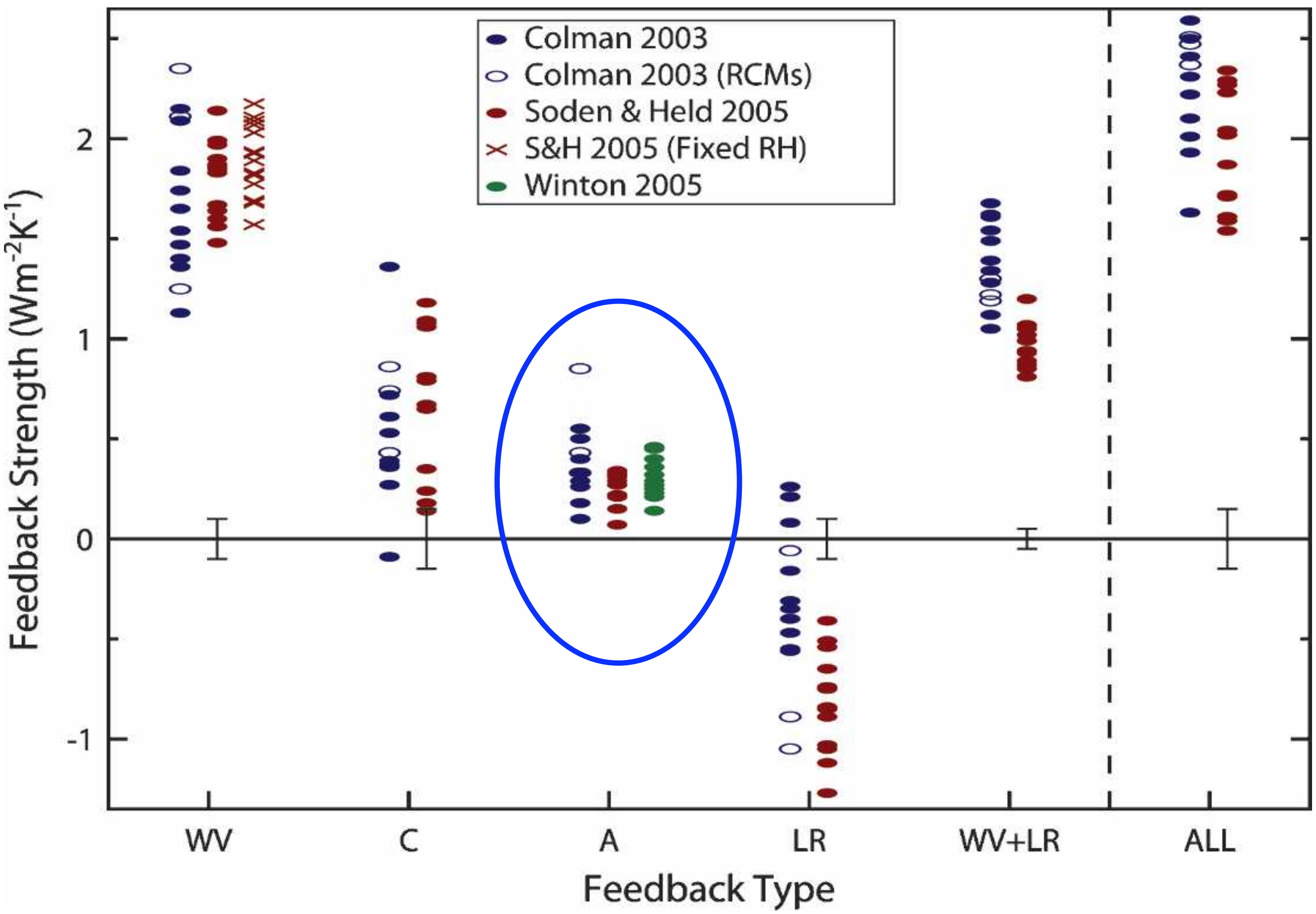
II. What Controls SAF Strength in models?

III. Constraining the feedback

IV. From Observational Constraint to True Validation and Model Improvement

V. Wild cards

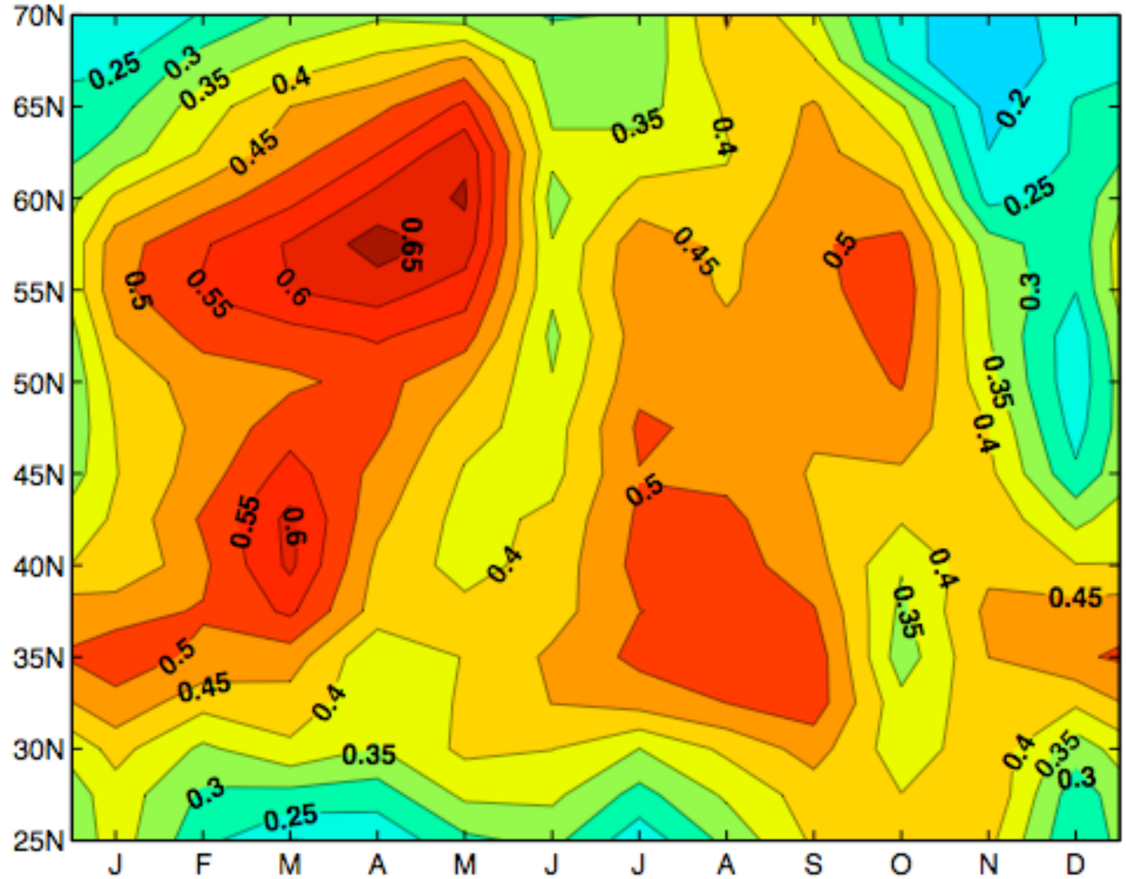
Comparison of Climate Feedbacks in the AR4 and earlier models



Bony et al. 2006

The surface albedo feedback term here contains northern and southern hemisphere contributions. The northern hemisphere contribution is divided into contributions from sea ice and snow. By this measure, snow albedo feedback, even though it exhibits a factor of three spread, is not particularly important for global climate sensitivity or its spread.

Consequences of the spread in snow albedo feedback in AR4 models



Correlation between zonal-mean temperature response over Northern Hemisphere land and springtime snow albedo feedback strength.

We've noted that in the AR4 models, snow albedo feedback strength exhibits a factor-of-three spread. Variations in snow albedo feedback strength account for a significant portion of the intermodel variations in temperature response over northern hemisphere landmasses. Signals are particularly large in spring and summer.

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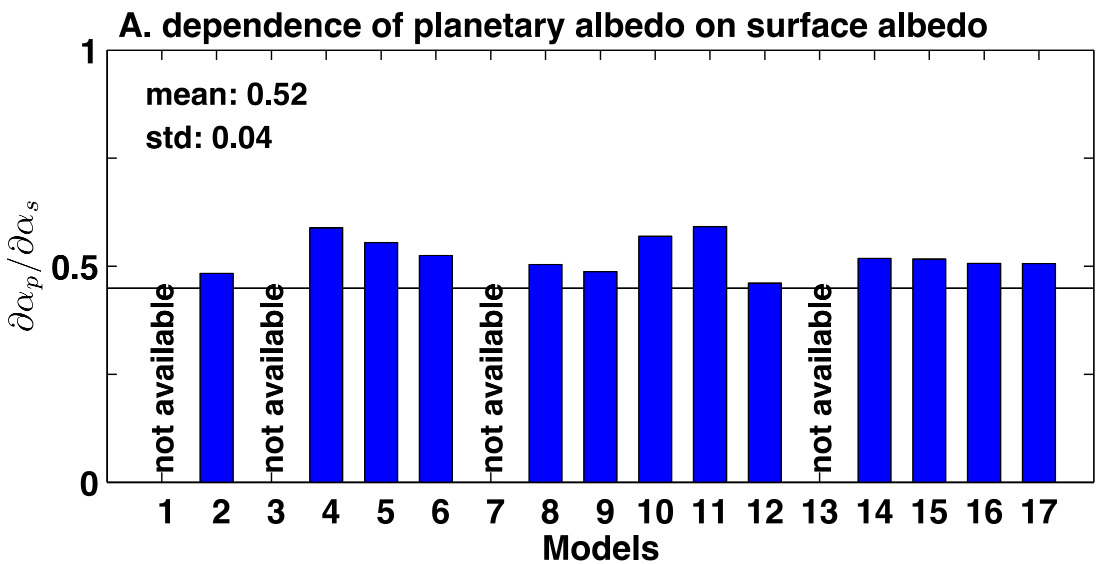
The two factors governing SAF strength in climate change



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Qu and Hall 2006

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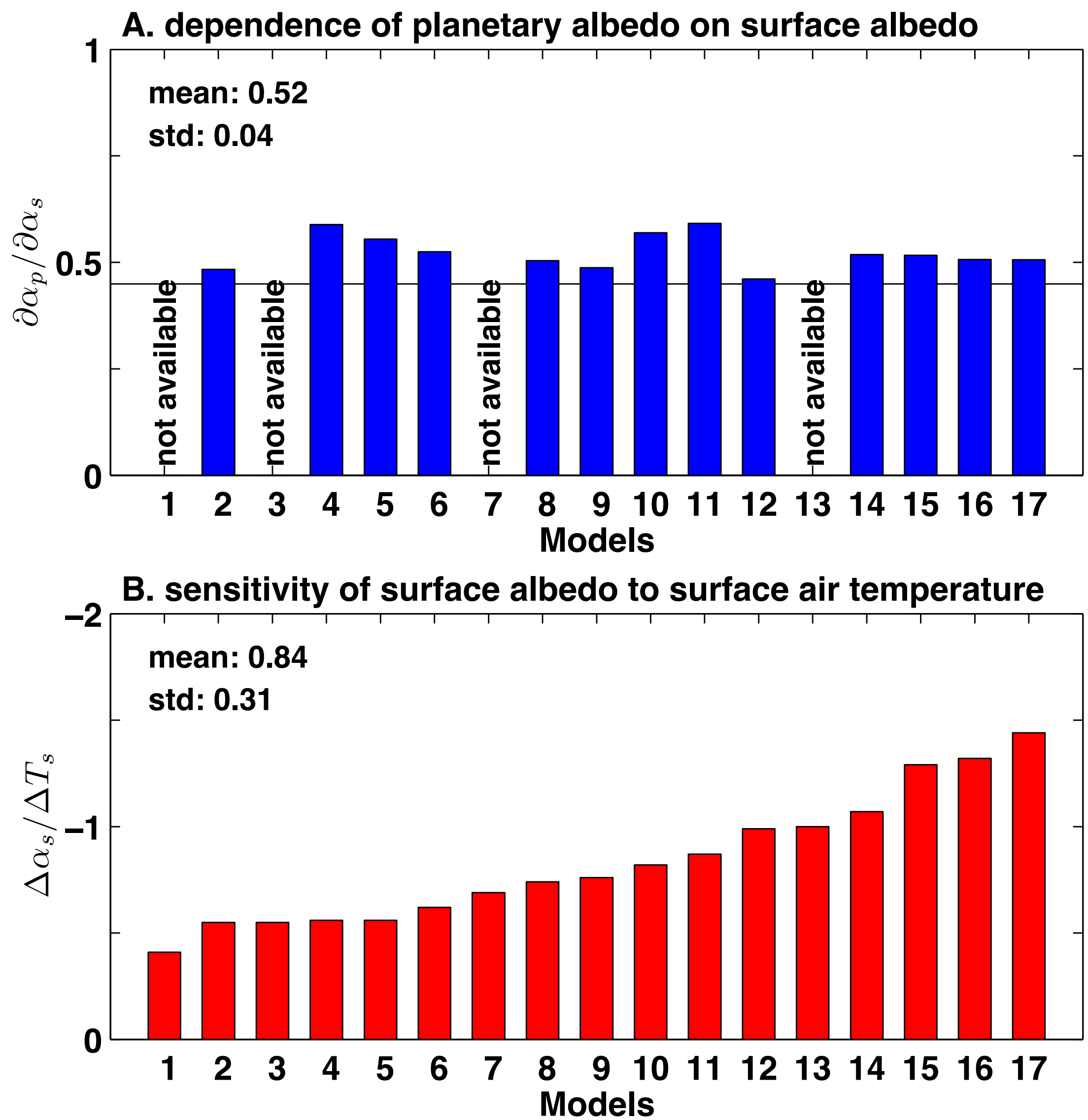

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dependence of planetary albedo on surface albedo

change in surface albedo with SAT

Nearly all the spread in SAF is concentrated in surface processes. The surface component can in turn be divided into 2 components: snow cover and snow metamorphosis…

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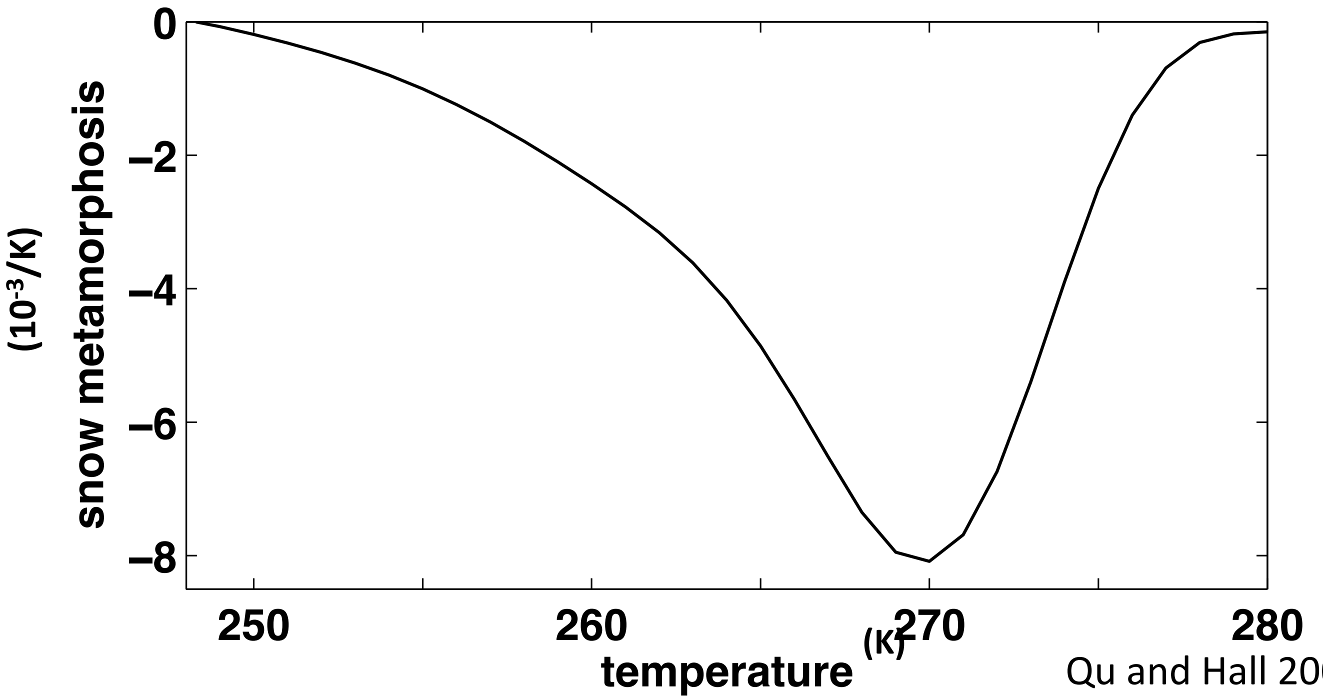
Snow albedo change due to metamorphosis in AR4 models



Qu and Hall 2007

The characteristic albedo sensitivity of 100%-snow-covered surfaces to temperature anomalies...

…is typically a function of mean temperature, with the albedo sensitivity being largest at or just below freezing.

In the models, snow metamorphosis effect is often parameterized through temperature and snow age in simple ways. Above is a composite function for all the AR4 models.

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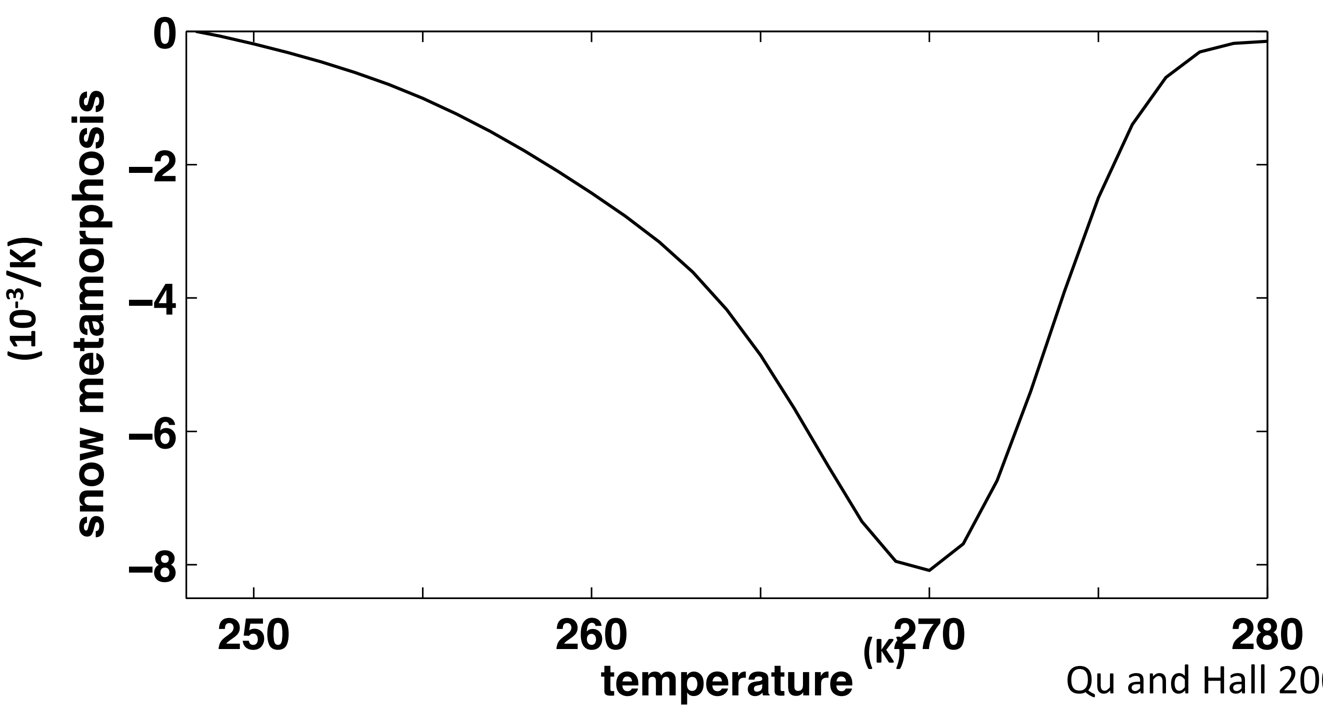

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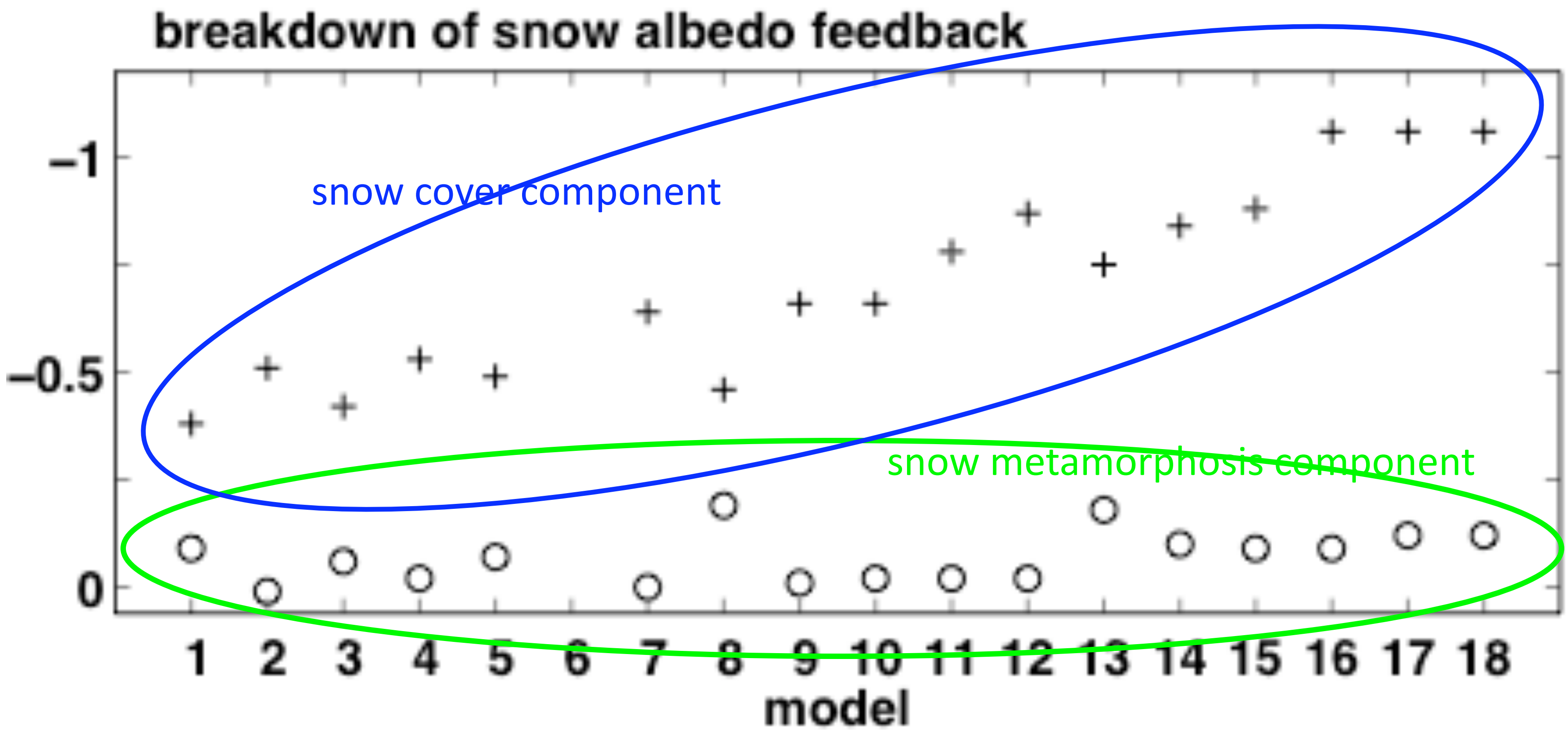
In the real world, snow metamorphosis is obviously more complicated, involving many processes such as initial size distribution, vertical temperature gradient, snow density, vapor diffusion caused by curvature differences, and irregularity in particle spacing (Flanner and Zender 2006). Is this an issue?

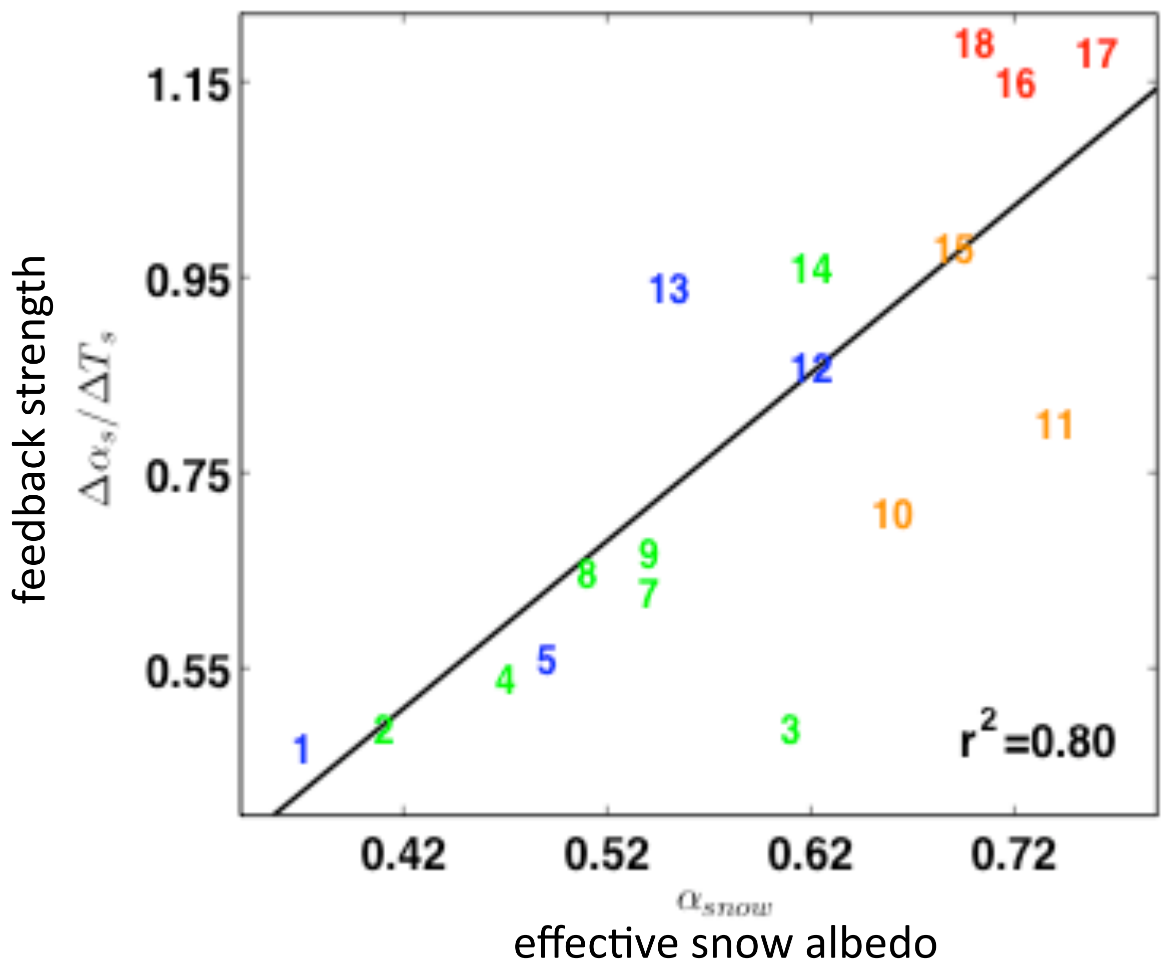
What controls the strength of the surface component of SAF?



It turns out that the snow cover component is overwhelmingly responsible not only for the overall strength of snow albedo feedback in any particular model, but also the intermodel spread of the feedback.

Qu and Hall 2007

The importance of the albedo of snow-covered surfaces…



Because of the dominance of the snow cover component in the AR4 models, SAF strength is highly correlated with a nearly three-fold spread in simulated effective snow albedo, defined as the albedo of 100% snow-covered areas. So we know what controls SAF strength, in models at least.

Qu and Hall 2007

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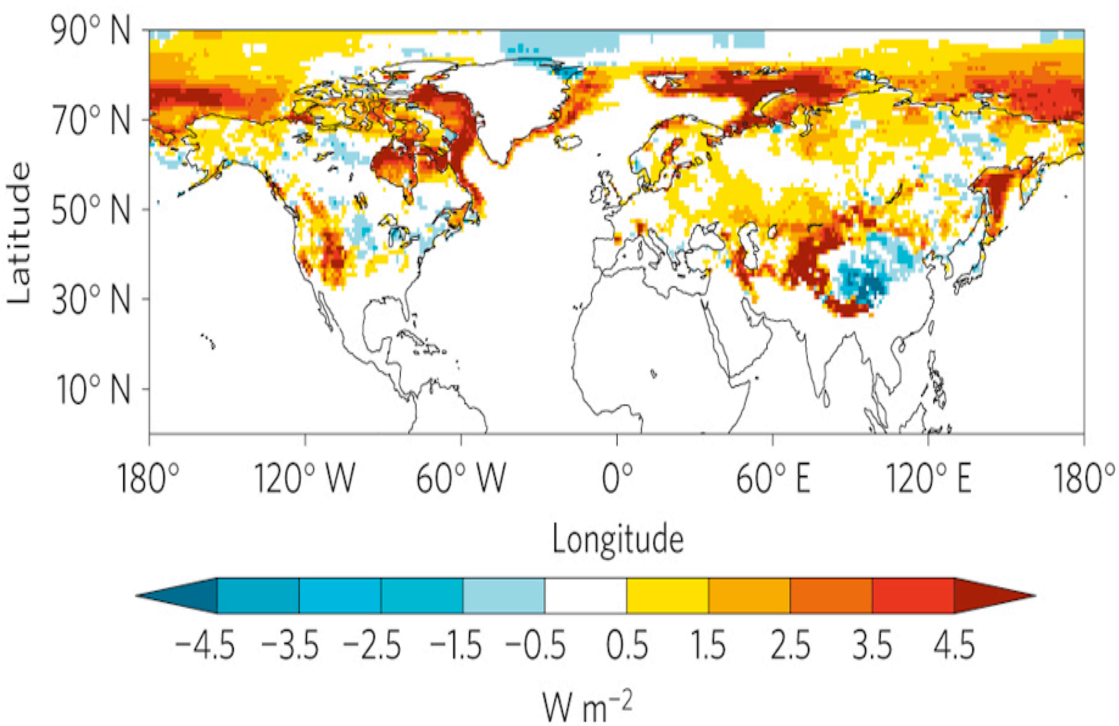
Efforts to constrain surface albedo feedback based on trends of the past few decades



The thirty-year changes in solar cryosphere forcing calculated from linear trends since 1979. Negative cryosphere forcing indicates that snow and ice decrease the net TOA solar energy flux. The predominance of positive values over land shows that the cryospheric cooling effect has decreased over land , **i.e. snow albedo feedback!** Clear evidence of sea ice albedo feedback is also seen.

Flanner et al. 2011

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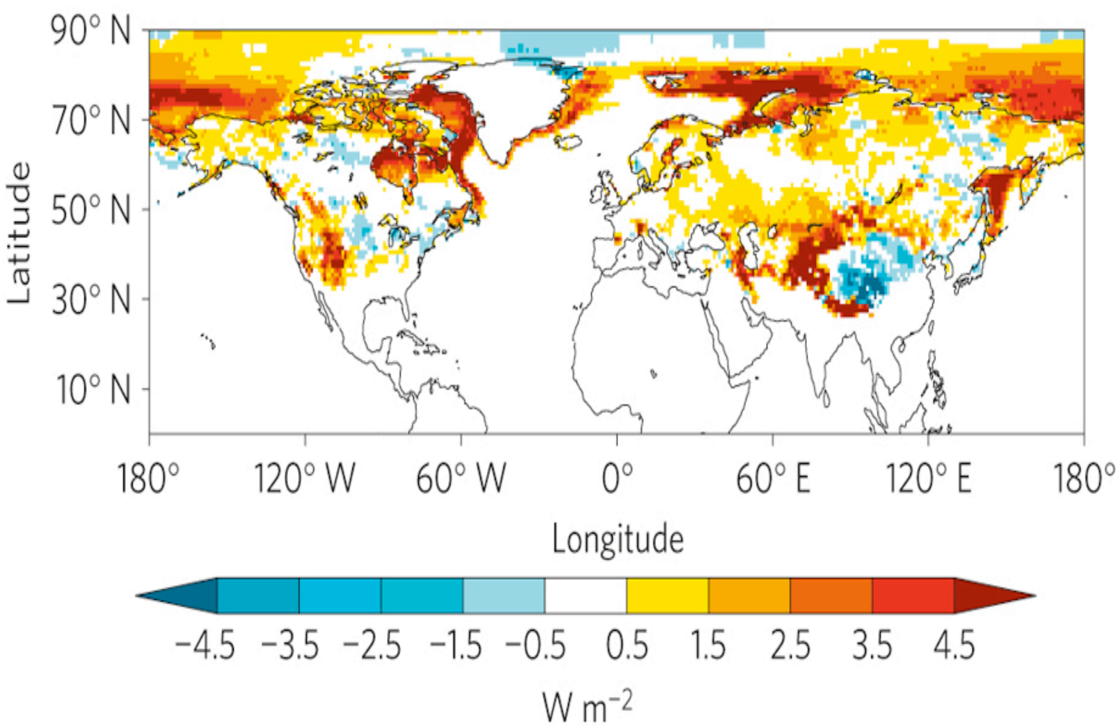

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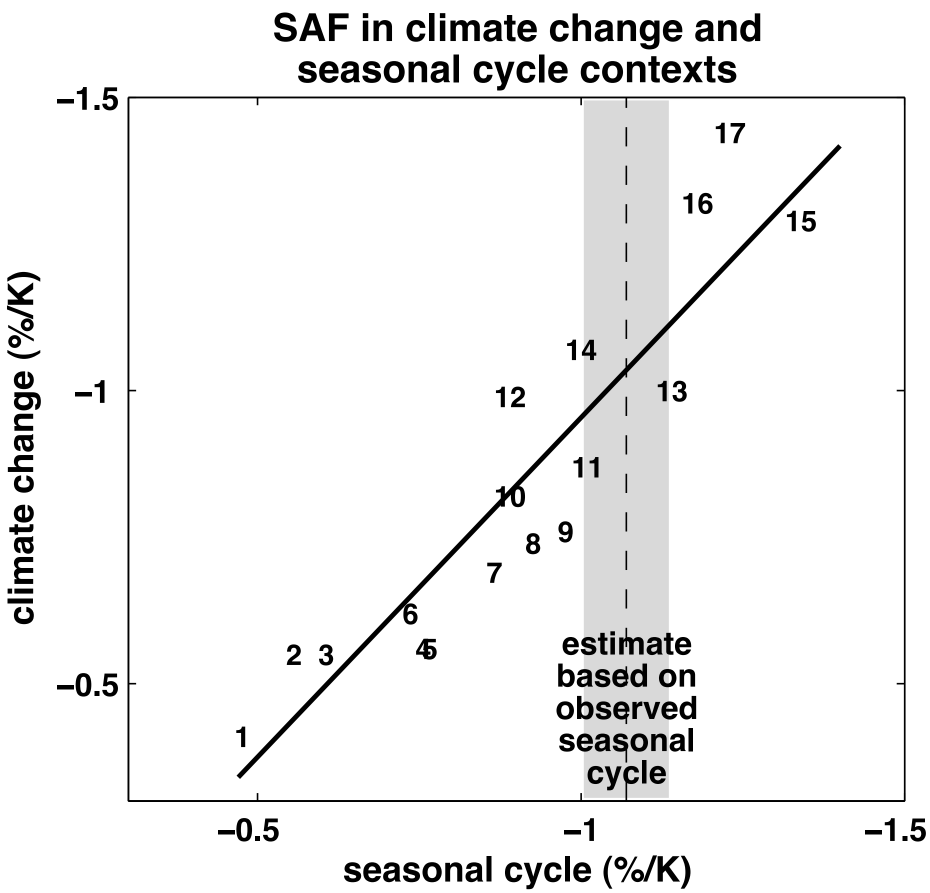
Even more interesting: The observed NH cryosphere albedo feedback is estimated to be 0.62 (0.33–1.07) W m^{-2} K^{-1}. Analyzing the AR4 models, they quantify a 1980–2010 NH model feedback of only 0.25 ± 0.17 W $m^{-2}K^{-1}$. How this bias is partitioned between snow albedo feedback and sea ice albedo feedback is unclear. (The recent sea ice loss is generally undersimulated in the AR4 models.)

The signals seen in Flanner et al 2011 are consistent with other studies showing decreasing trends in snow cover over comparable time periods, e.g. Déry and Brown 2007.

Efforts to constrain SAF based on the seasonal cycle

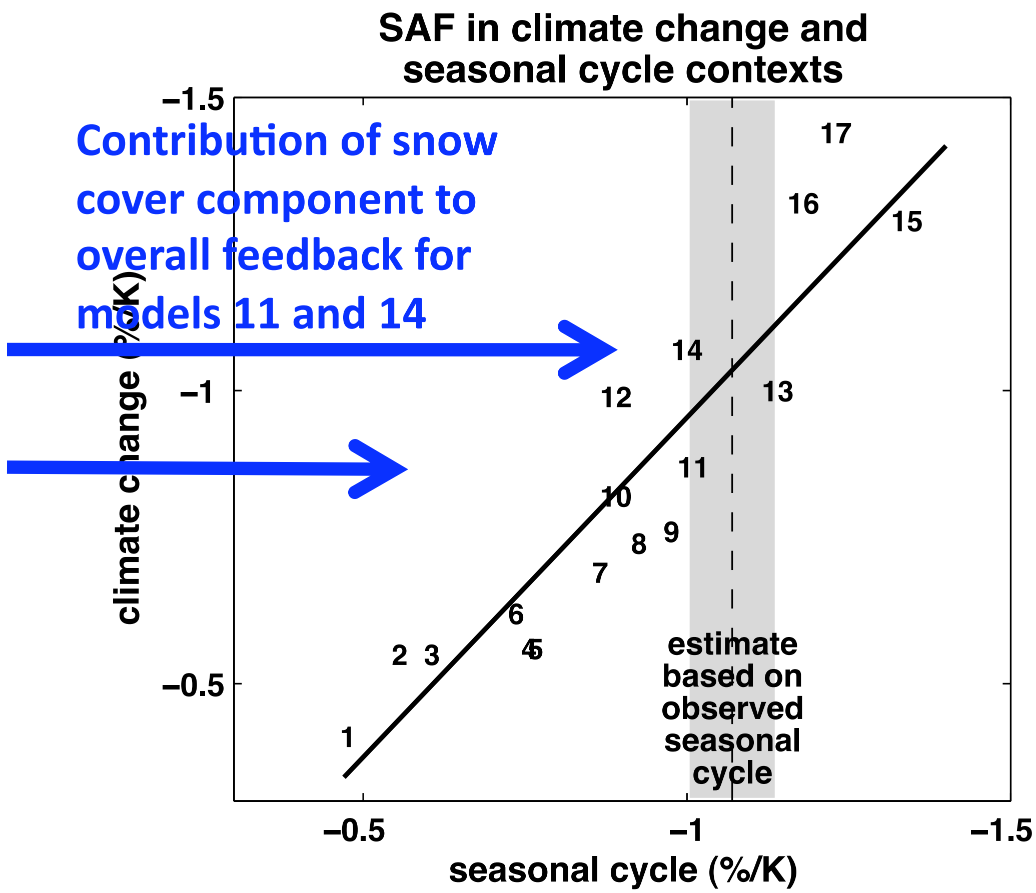


Scatterplot of the sensitivity of surface albedo to surface air temperature in climate change (ordinate) vs. the same quantity in the seasonal cycle

Note that Pedersen and Winther (2005) show that models often underestimate surface albedo in areas with snow. This would weaken the snow cover component of SAF, possibly accounting for the bias towards an SAF that is somewhat too weak.

Hall and Qu 2007

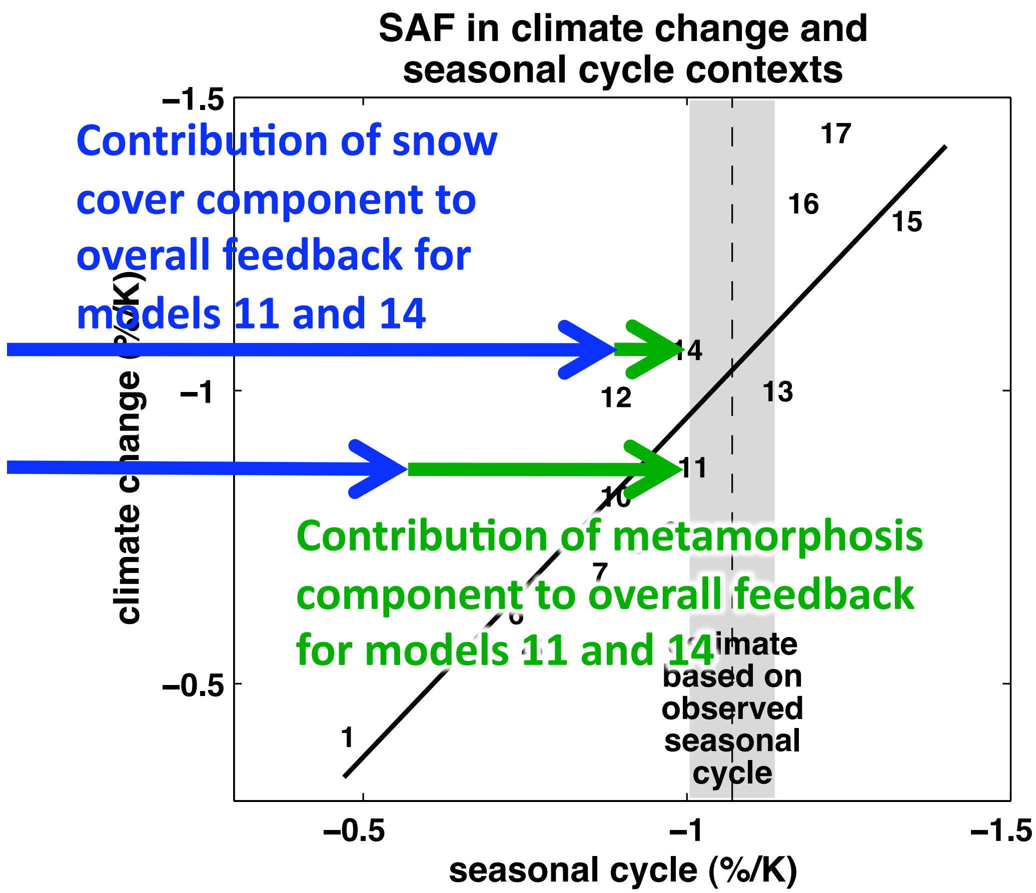
Pathways to model realism



Scatterplot of the sensitivity of surface albedo to surface air temperature in climate change (ordinate) vs. the same quantity in the seasonal cycle

Suppose the blue arrow above represent the contribution of the snow cover component to the total snow albedo feedbacks of models 11 and 14. Notice they are different even though models 11 and 14 both have a feedback strength that is realistic overall.

Pathways to model realism



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We can imagine more than one combination of **snow cover** and **snow metamorphosis** components could produce a realistic overall feedback. The case illustrated above may be unlikely. Still we need to validate the two components individually, to validate the feedback.

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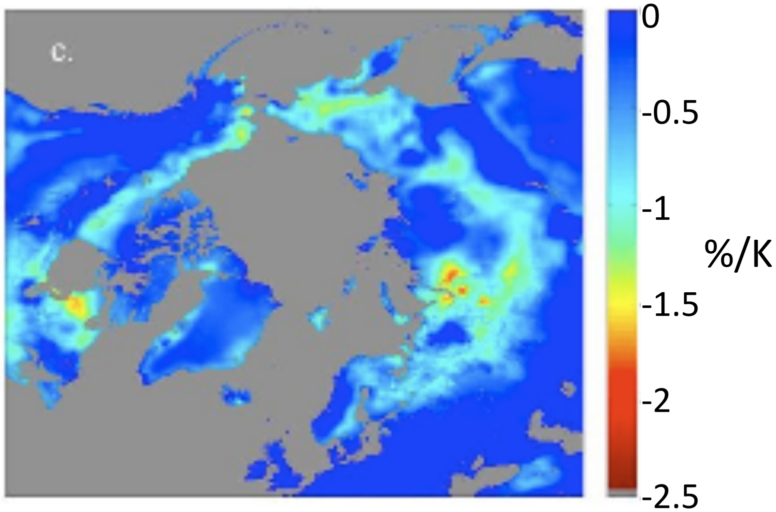
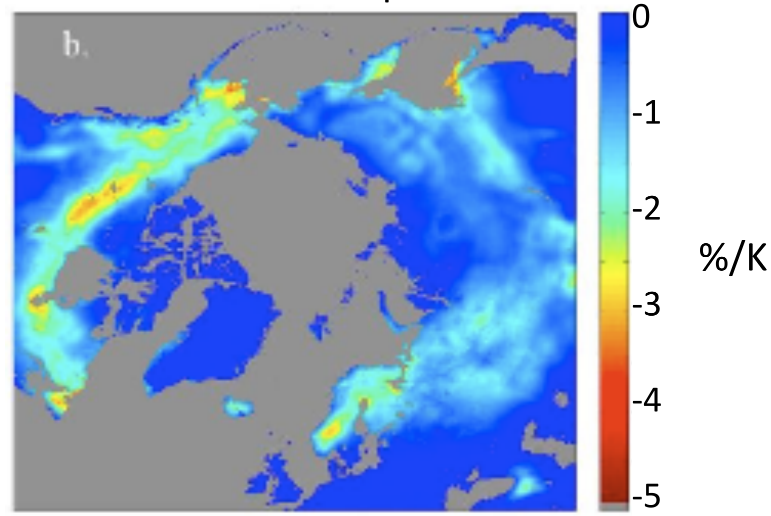
Spatial patterns of SAF based on the observed seasonal cycle (April-May)

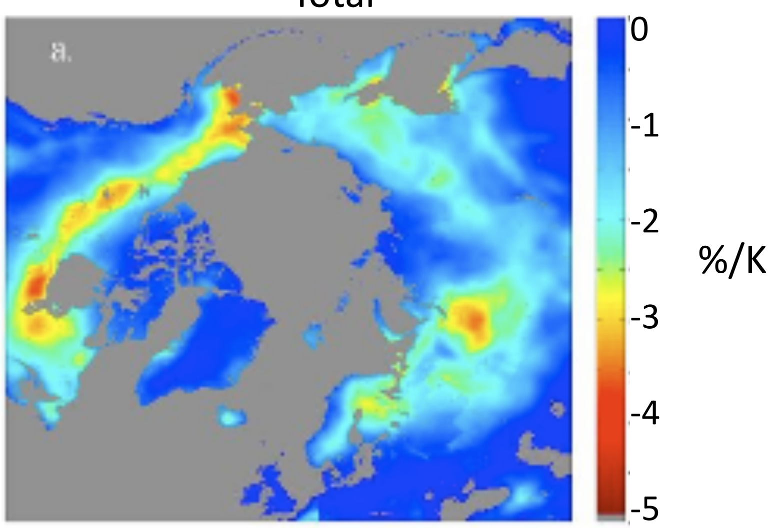
Snow metamorphosis component



Snow cover component



Total



The AVHRR-based surface albedos averaged over the first 30 snow-free dates after the date of spring snow melt were used to estimate land albedo.

Land albedo, surface albedo over snow-covered surface and satellite-measured snow cover are used to estimate snow albedo.

Snow cover and metamorphosis components of SAF are estimated based on land albedo, snow albedo and snow cover in April and May.

Fernandez et al 2009

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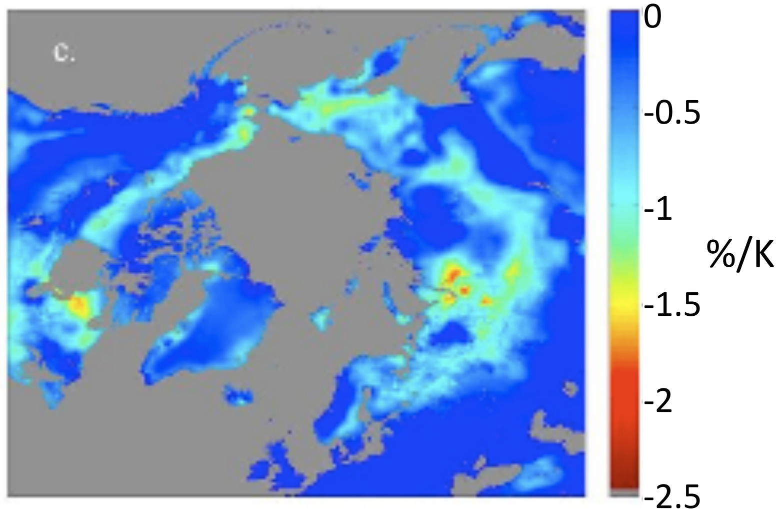
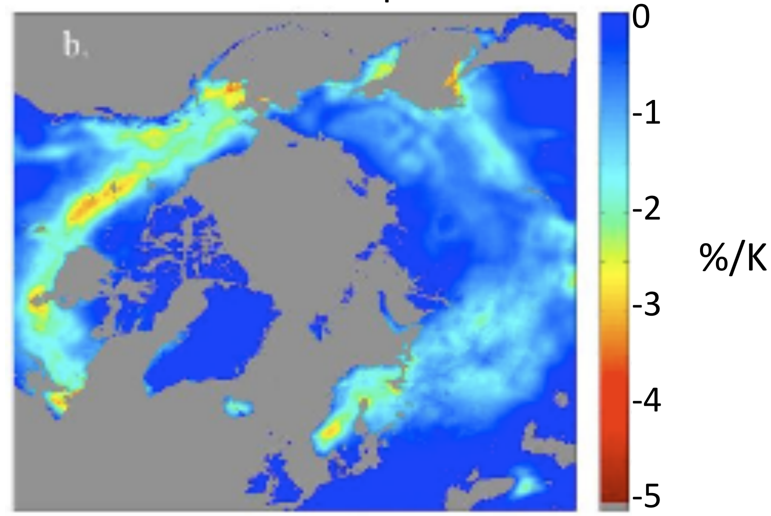


Snow cover component



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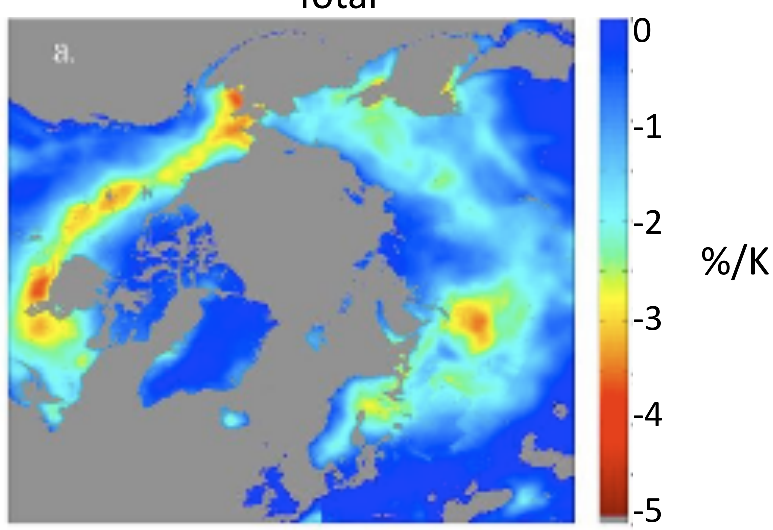
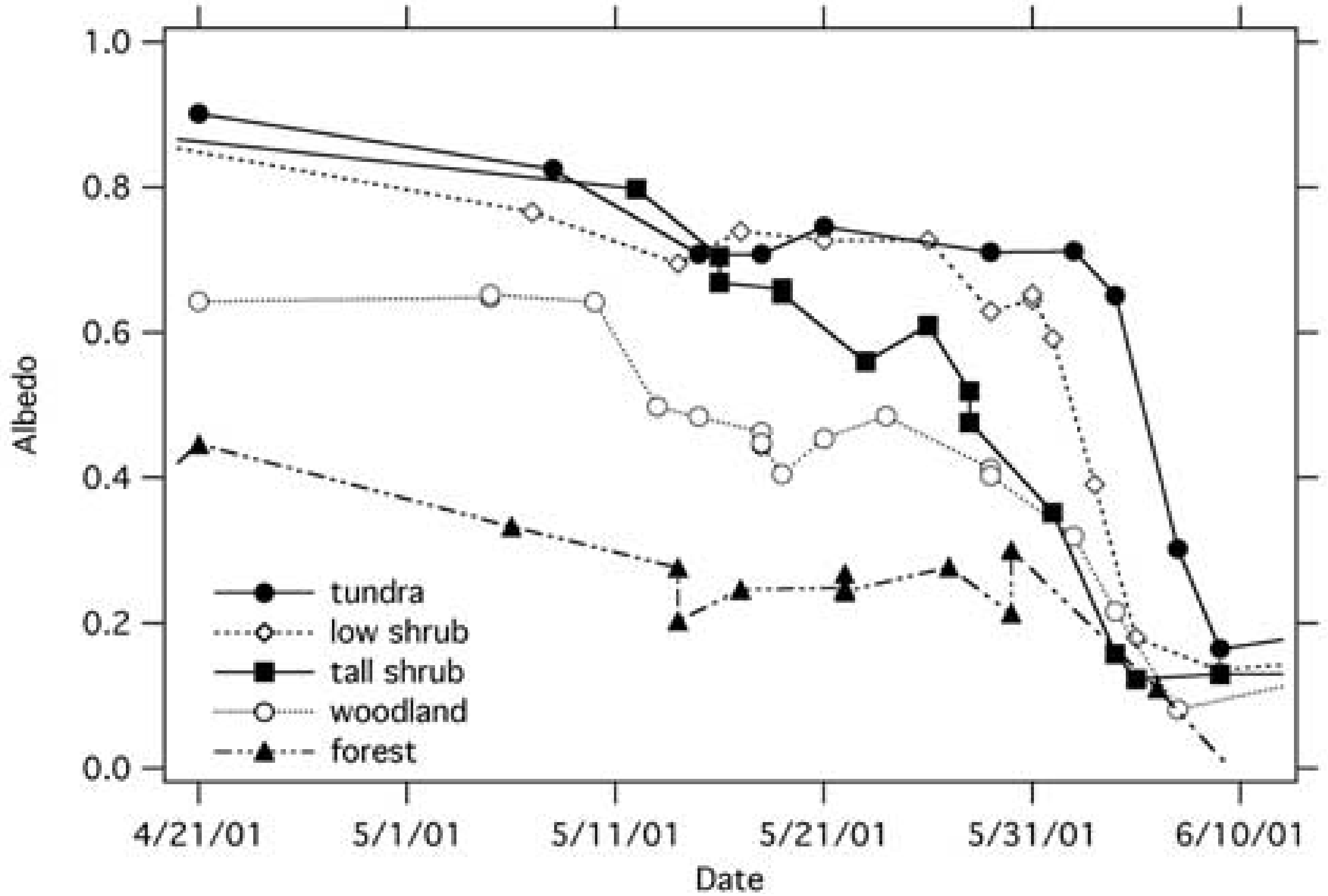


The snow cover component is generally larger than the snow metamorphosis component, but perhaps not an order of magnitude larger, especially over Eurasia. To date, these numbers have not been systematically compared with models.

But even if the two components were individually validated, it is still challenging to improve the models based on the validation, because of the evolving formalism of surface albedo parameterization.

Fernandez et al 2009

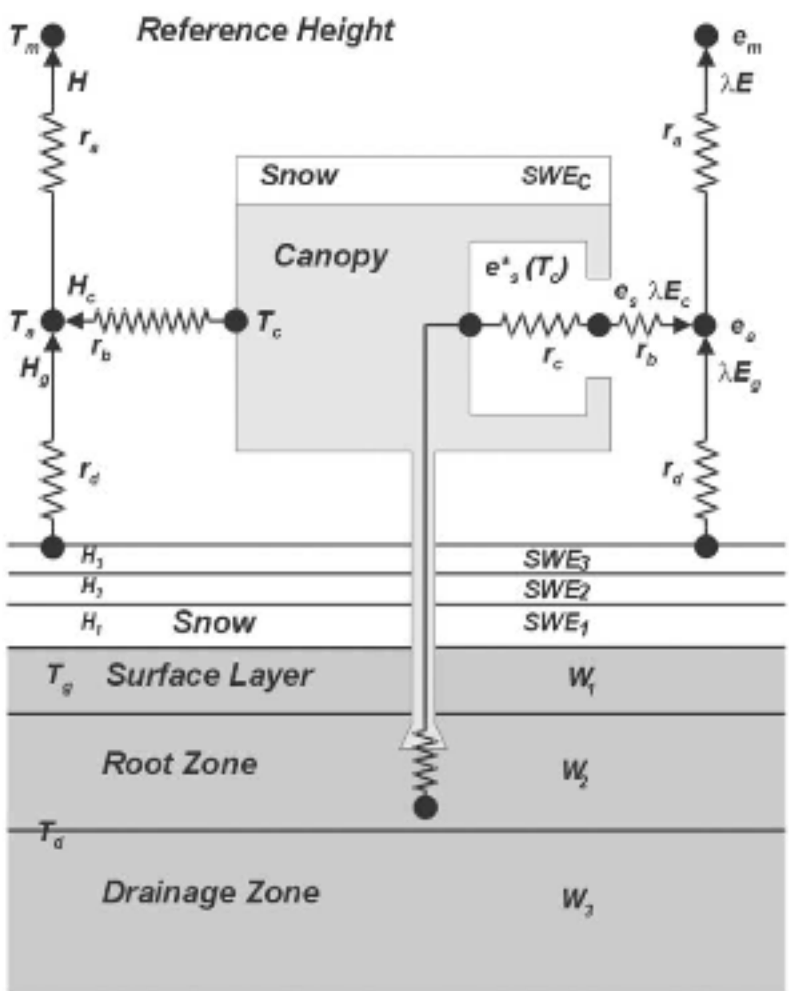
Some background of surface albedo parameterization:
Effect of vegetation type on albedo in snow conditions



In situ measurements (Sturm et al. 2005)

Evolution of local albedo at the five study sites during the melt season for 2001. The albedo at sites with exposed shrubs (or trees) began to decay earlier in the melt period, but at rates that were lower than at sites with little or no exposed shrubs. In 2002, no measurements were available from the woodland site, but otherwise, a similar pattern was observed.

Further Background: Surface-albedo Parameterizations in the AR4 models



Xue et al. 1996, 2003

In the AR4 models, the surface albedo schemes can be grouped into four categories according to the way the masking effect of vegetation is treated. In order of decreasing complexity:

1: a full-blown canopy radiative transfer model (see example at left).

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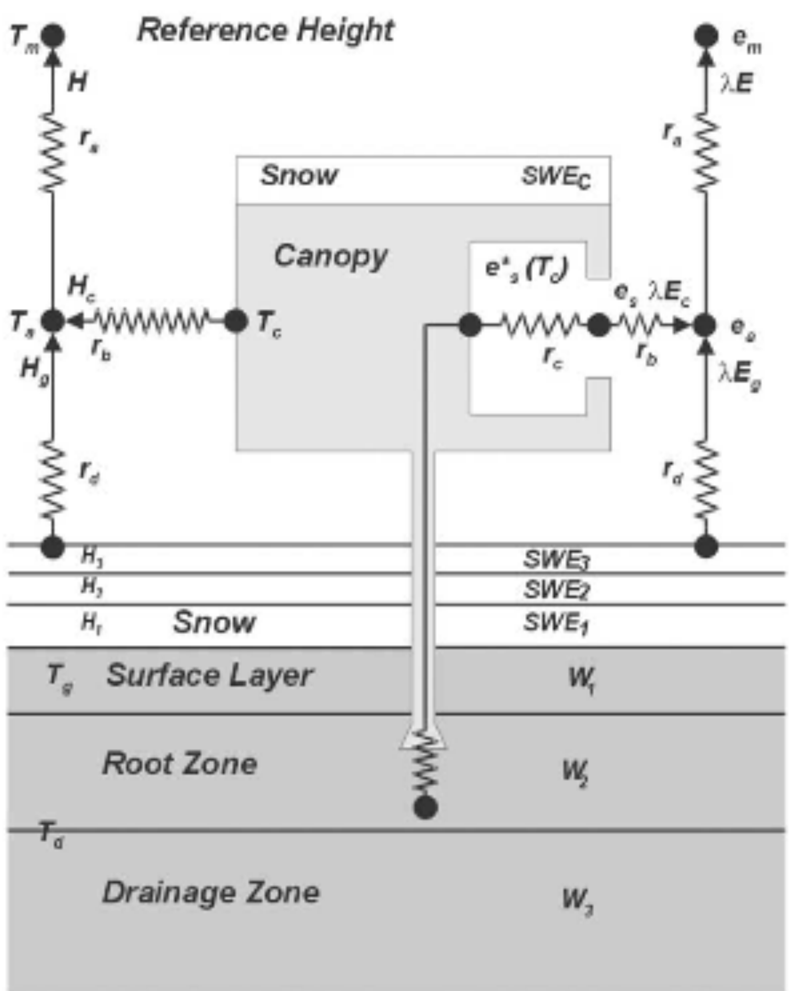

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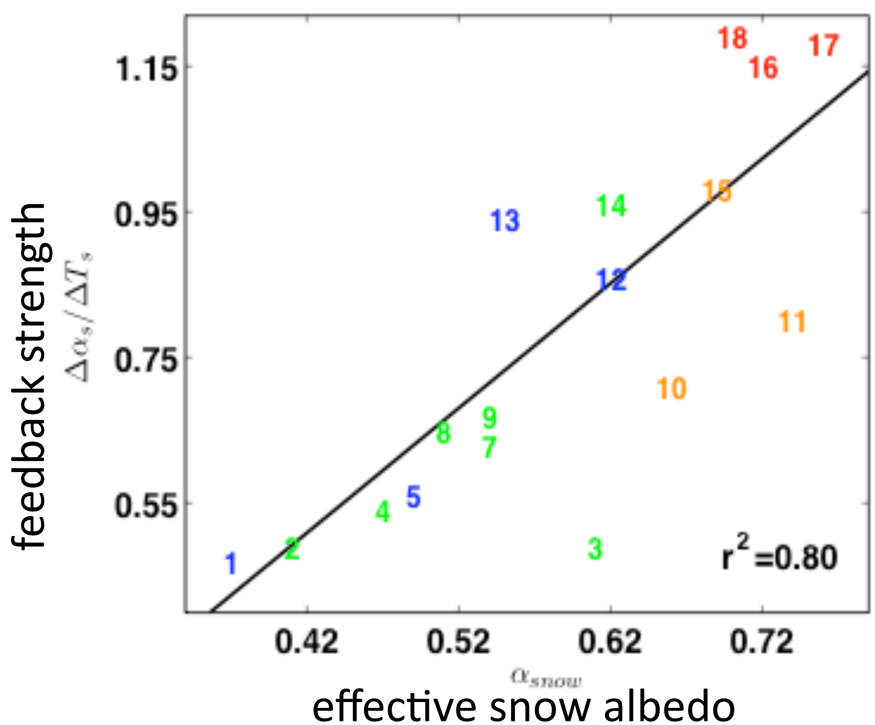
1: a full-blown canopy radiative transfer model (see example at left).

2: canopy albedo is prescribed according to vegetation type and then modified depending on whether snow is sticking to the canopy, and the overall surface albedo is a weighted mean of canopy albedo and ground albedo.

3,4 : the canopy and ground albedos are not treated separately, and the overall surface albedo is simply a weighted mean of snow-free surface albedos and snow albedo. **In the type 3 schemes, the snow albedo depends on vegetation type, while the type 4 schemes are even simpler, with snow albedos independent of vegetation type.**

And a brief detour into the sociology of climate modeling…



The more complex models tend have systematically lower snow albedos, and the best information we have suggests these models may have unrealistically low snow albedos. What to do?

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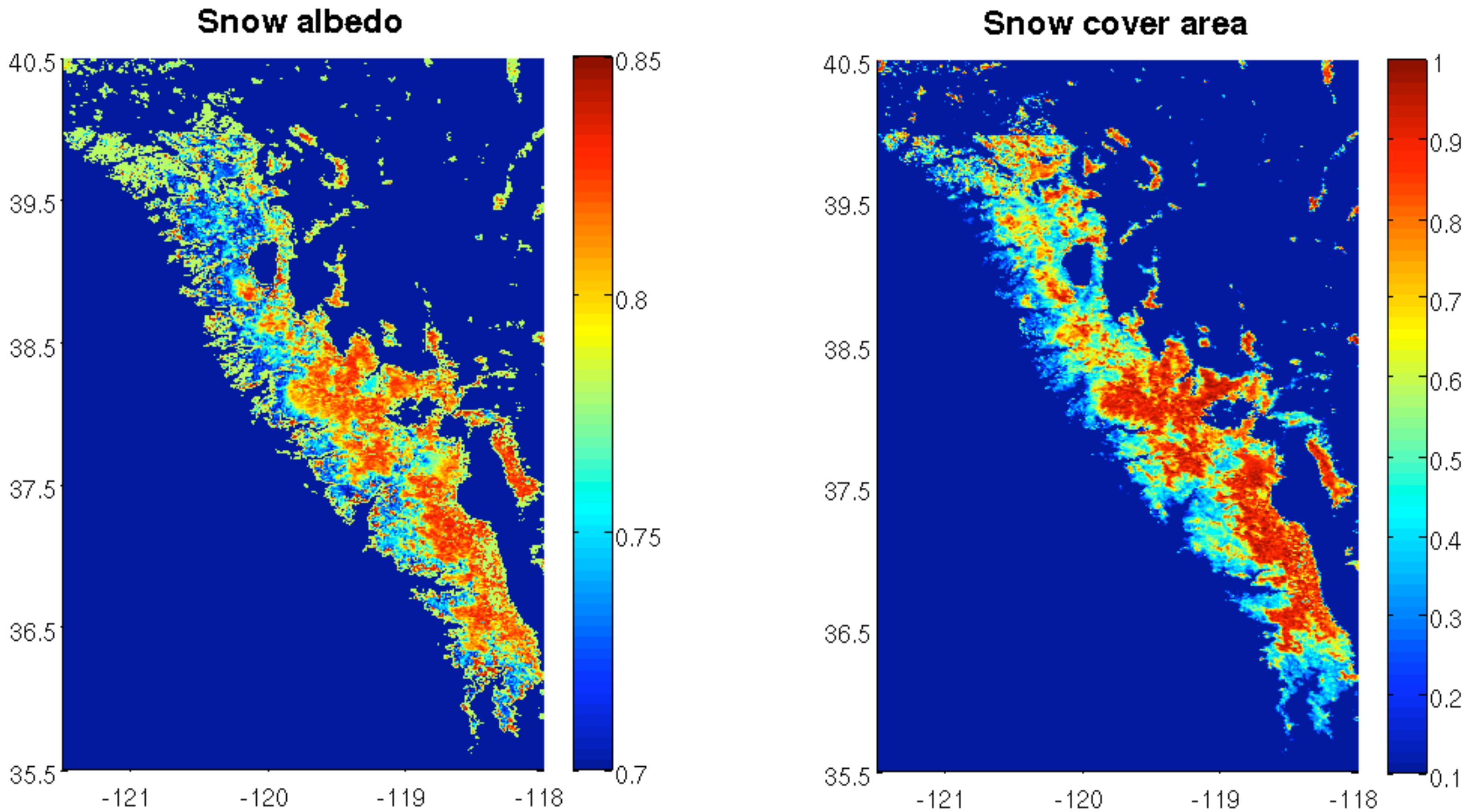
Qu and Hall 2007

The state-of-the-art in snow albedo observation



MODIS-based estimates (MODSCAG method) in the California Sierra Nevada Jan 2002 – from Tom Painter

In this scene, it is clearly possible to discriminate between albedos of 100% snow-covered surfaces based on the surface type. Snow-covered bare rock has the highest albedo, while snow zones below the tree line have somewhat lower albedos. This type of high-resolution surface-type-specific information should provide adequate statistics to validate and improve even land surface models with the most sophisticated canopy treatment.

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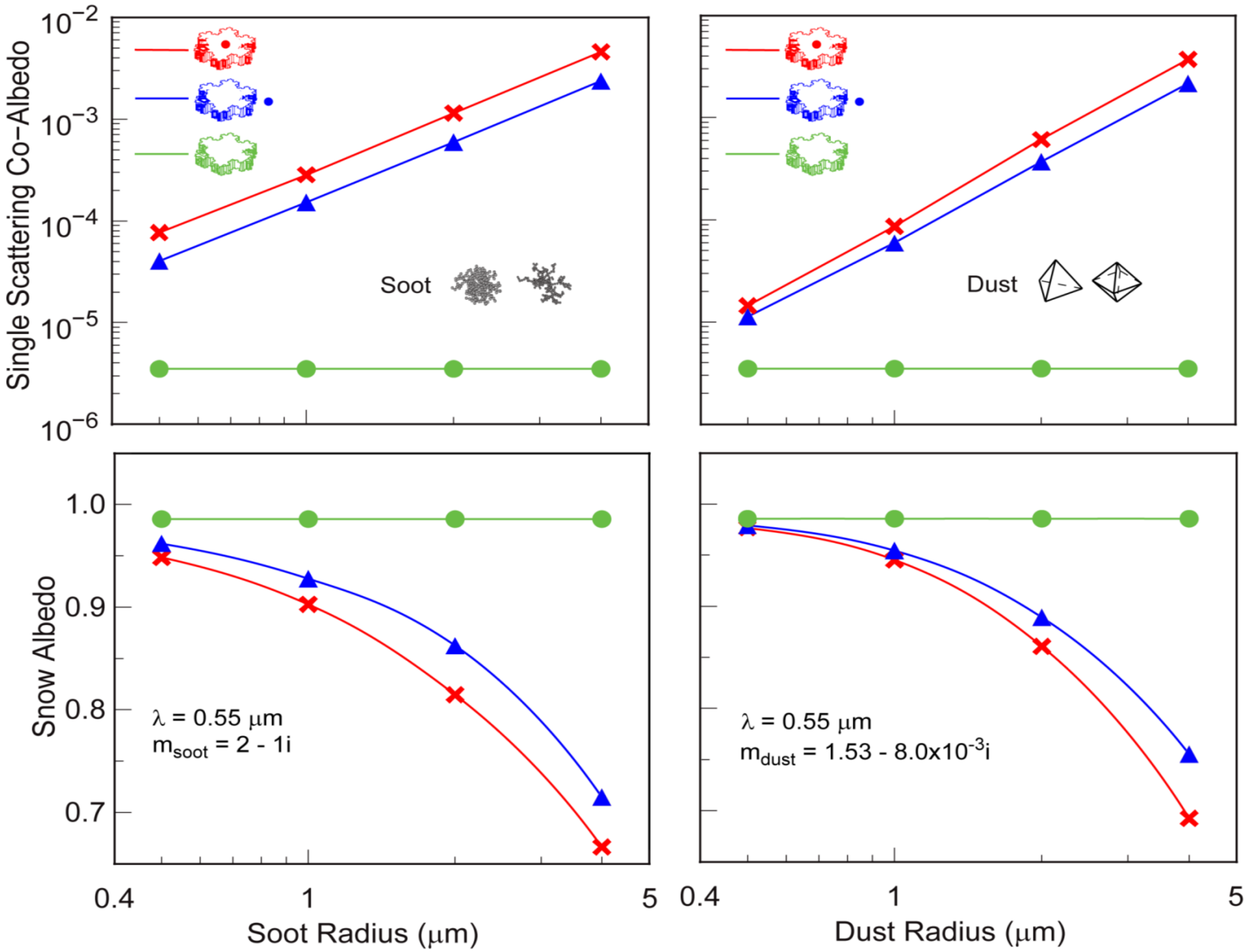
Effect of dust and aerosols



Visible single-scattering co-albedo (the ratio of absorption and extinction coefficients) and snow albedo as a function of soot and dust equivalent radii for a snow grain of 50 μm in equivalent radius for pure and contaminated conditions (μ_0 = 0.5 and optically semi-infinite snow layer). Large differences in snow albedo are shown with external and internal mixing cases. A 1 μm soot particle internally mixed with snow grains could effectively reduce snow albedo as much as 5-10% (Liou et al. 2011).

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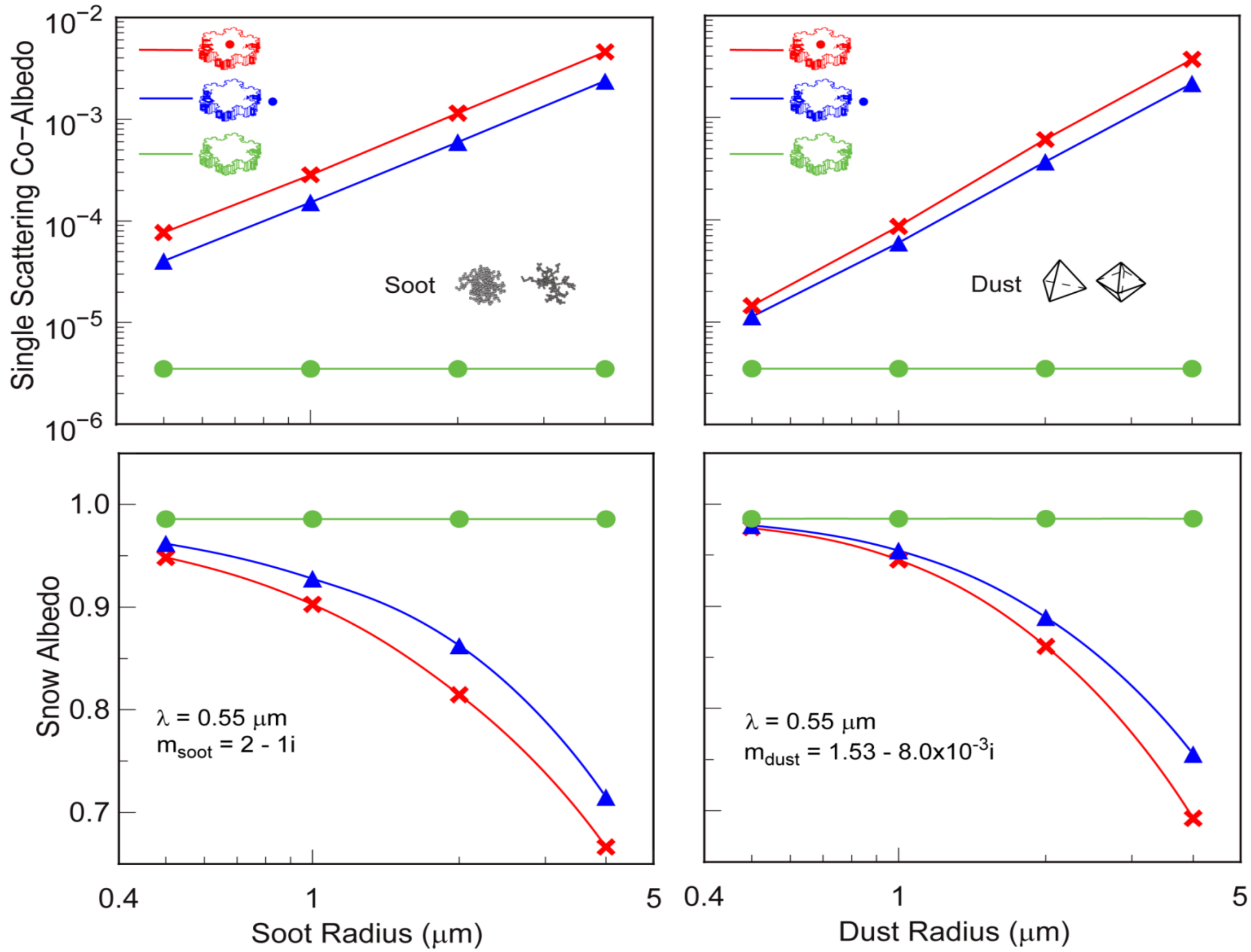

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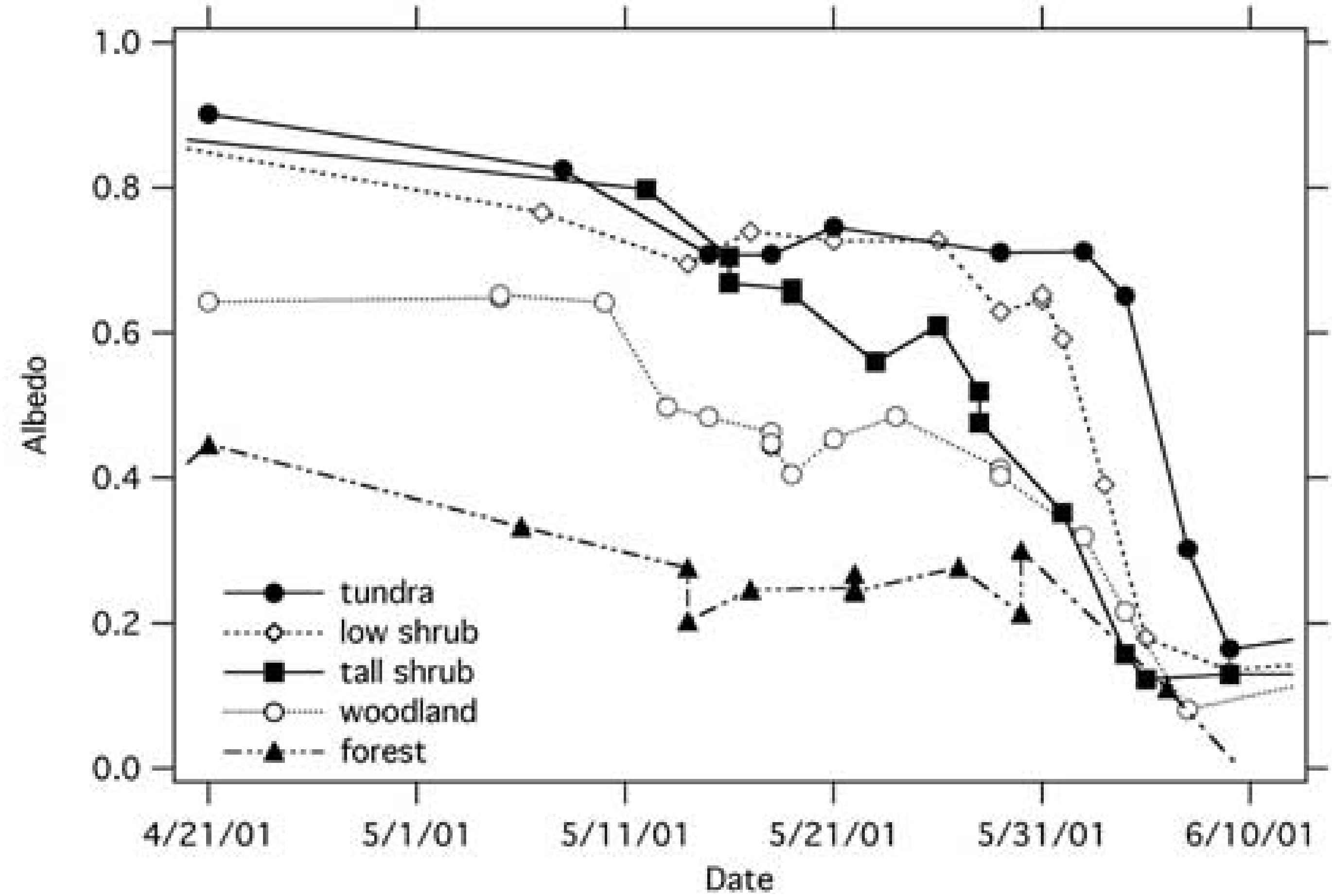
Various estimates of the climate forcing effect of soot on snow and ice albedos have shown that it is not negligible compared to other climate forcings (e.g. Hansen and Nazarenko 2004, Flanner et al. 2007, Jacobson 2004, Qian et al. 2009)

These effects will need to be taken into account in efforts to improve surface albedo parameterizations, because the observations will certainly include them, and models may or may not. Care will have to be taken to ensure these effects are handled in a self-consistent manner.

Effect of vegetation type on albedo in snow conditions



In situ measurements (Sturm et al. 2005)

Vegetation types may shift under a changing change, and affect surface albedo in snow conditions, and hence snow albedo feedback. Preliminary calculations indicate this uncertainty is small compared to the other uncertainties surrounding snow albedo feedback, but it is possible dynamic vegetation models would be needed to evaluate this effect in detail.

VI. Conclusions

- Snow Albedo Feedback is a critical influence on climate change projections in Northern Hemisphere land masses, and exhibits a 3-fold spread in the AR4 models.
- The feedback can be divided into two components, snow cover and snow metamorphosis. The snow cover component dominates in both models and observations.
- Methods developed to compare to observations suggest the feedback may be somewhat on the low side in the models.
- Complete validation of the feedback would involve comparisons of both components to observations.
- Land surface models and surface albedo measurements are maturing rapidly and in parallel, and validation leading directly to model improvement should be possible in the near term.
- A couple of potential stumbling blocks remain, including effects of dust and aerosols, and impacts of shifting vegetation in a changing climate.