Contribution of Clouds to Seasonal Cycle of Surface Warming

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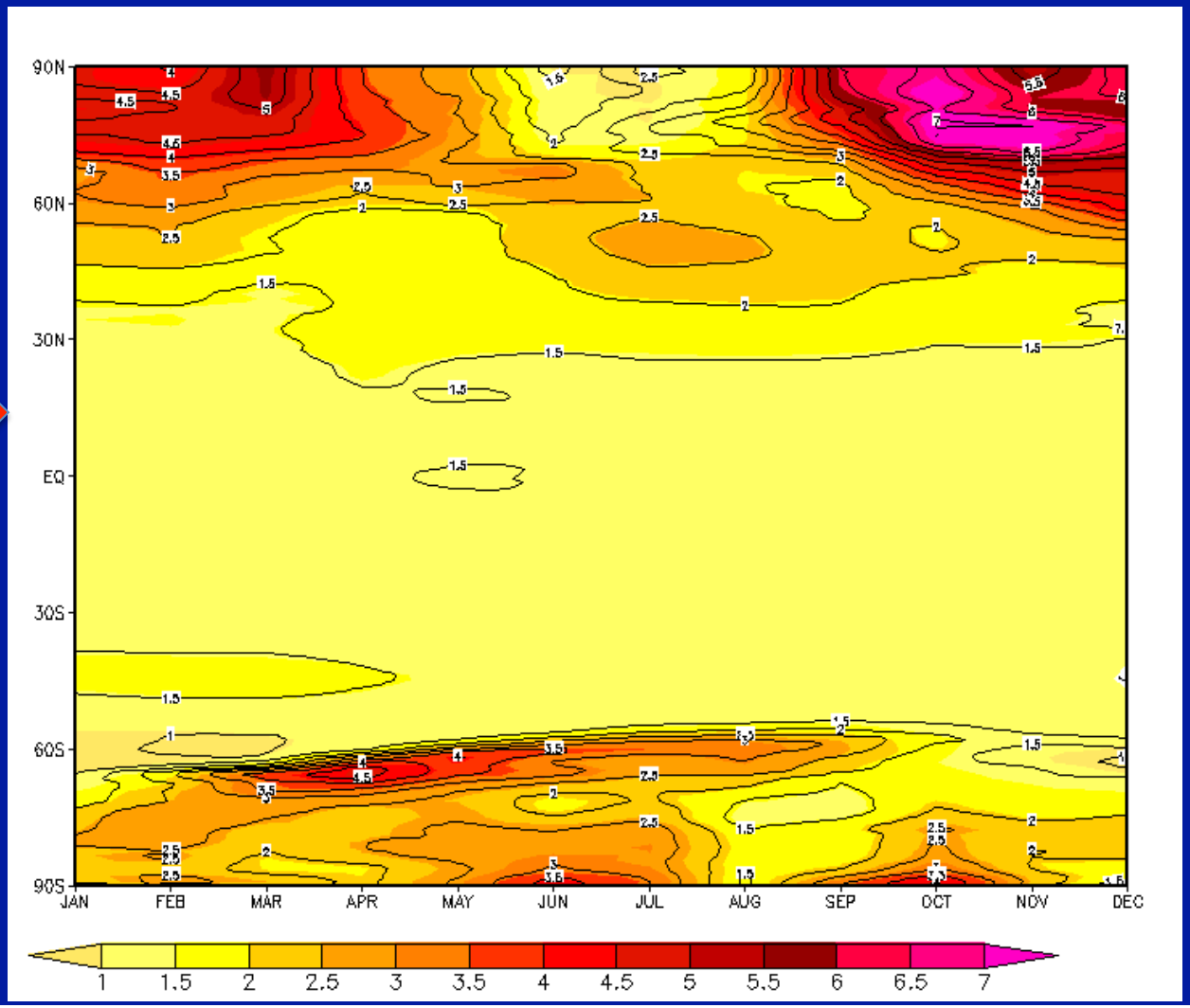
Seasonal Temperature Response to 2xCO_2 Forcing in NCAR CCSM4 Climate Simulations

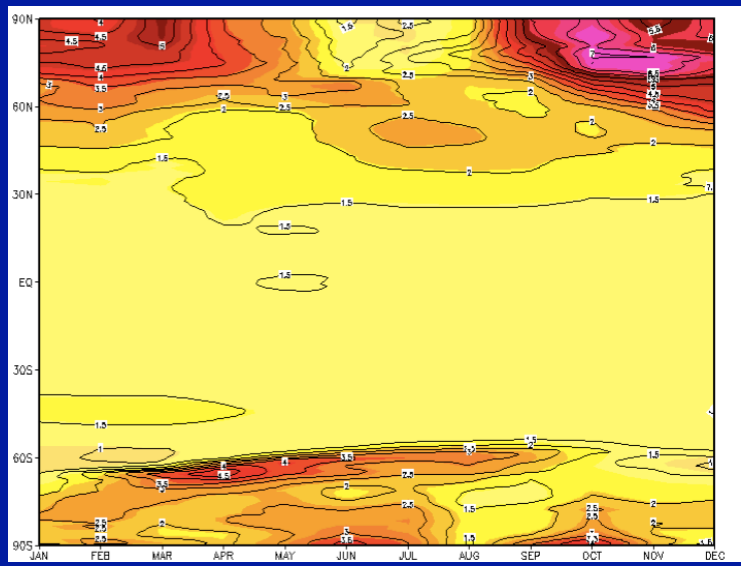
(at the time of CO_2 doubling from its pre-industry level 284.7 PPM at 1%/yr increase)

Seasonal Cycle of Surface Temperature Change



Questions

- If surface albedo feedback is thought to cause polar warming amplification, why doesn't the largest warming occur in summer?
- What are the contributions of cloud feedbacks to the total surface temperature change?
- What are the feedbacks responsible for the pronounced seasonality in polar regions?
- Why is there a lack of seasonal variability in the tropics?



Coupled Atmosphere-Surface Climate Feedback-Response Analysis Method (CFRAM) for CGCM Feedback Analysis

Lu and Cai (2009) and Cai and Lu (2009)

$$\Delta\vec{\mathbf{T}}^{tot} = \left(\frac{\partial\vec{\mathbf{R}}}{\partial\vec{\mathbf{T}}}\right)^{-1} \{\vec{\mathbf{F}}^{2CO_2} + \Delta^{(\alpha)}\vec{\mathbf{S}} + \Delta^{(c)}(\vec{\mathbf{S}} - \vec{\mathbf{R}}) + \Delta^{(wv)}(\vec{\mathbf{S}} - \vec{\mathbf{R}})$$

$$+ \Delta\vec{\mathbf{Q}}^{evaporation} + \Delta\vec{\mathbf{Q}}^{sfc_shflx} + \Delta\vec{\mathbf{Q}}^{Atm_Dyn} + \Delta\vec{\mathbf{Q}}^{Ocn_Dyn+storage}\}$$

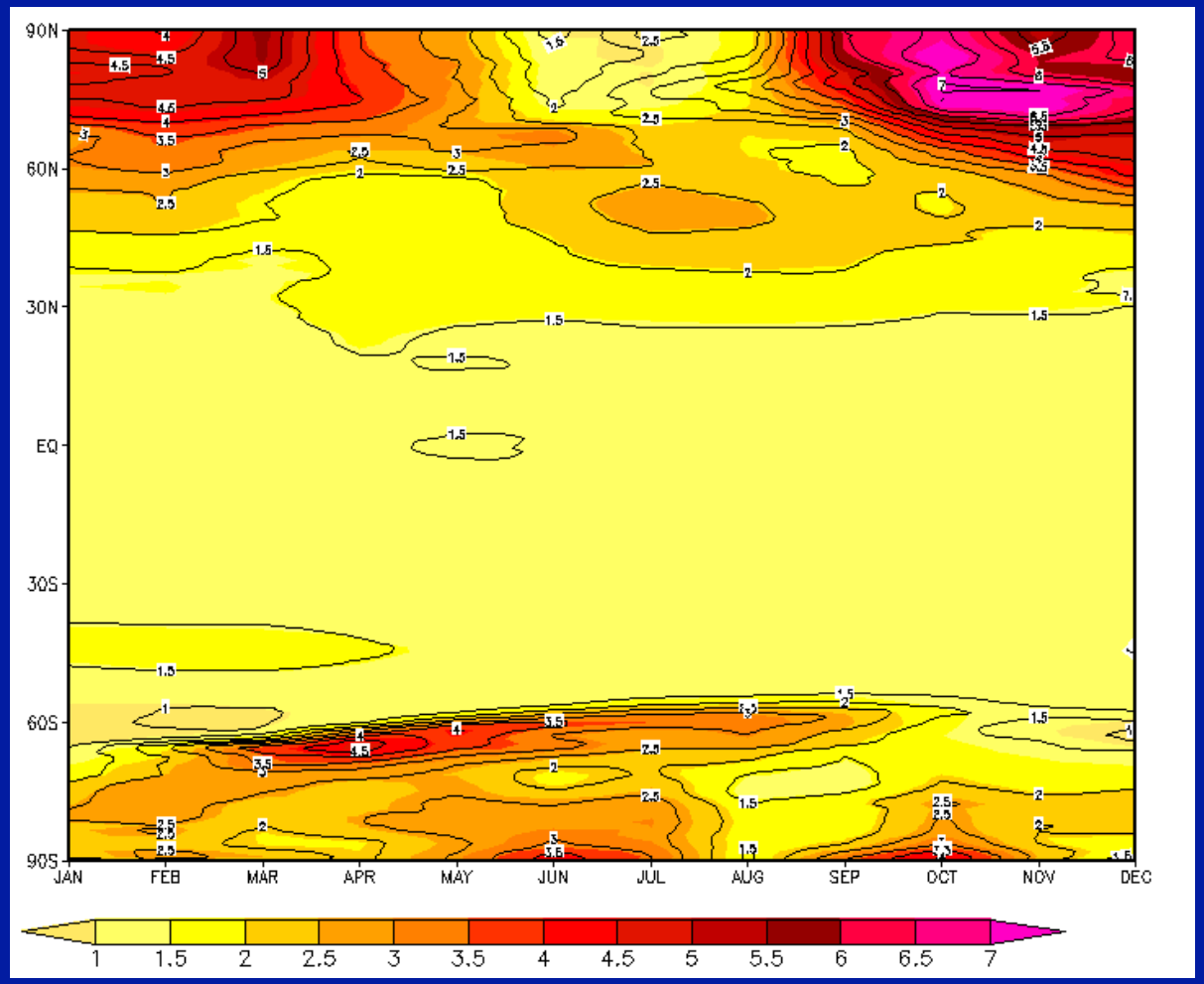
$$\Delta\vec{\mathbf{T}}^{(n)} = \left(\frac{\partial\vec{\mathbf{R}}}{\partial\vec{\mathbf{T}}}\right)^{-1} \Delta\vec{\mathbf{F}}^{(n)}$$

$$\Delta\vec{\mathbf{T}}^{tot} = \sum_{n} \Delta\vec{\mathbf{T}}^{(n)}$$

Both feedbacks and their effects are additive!

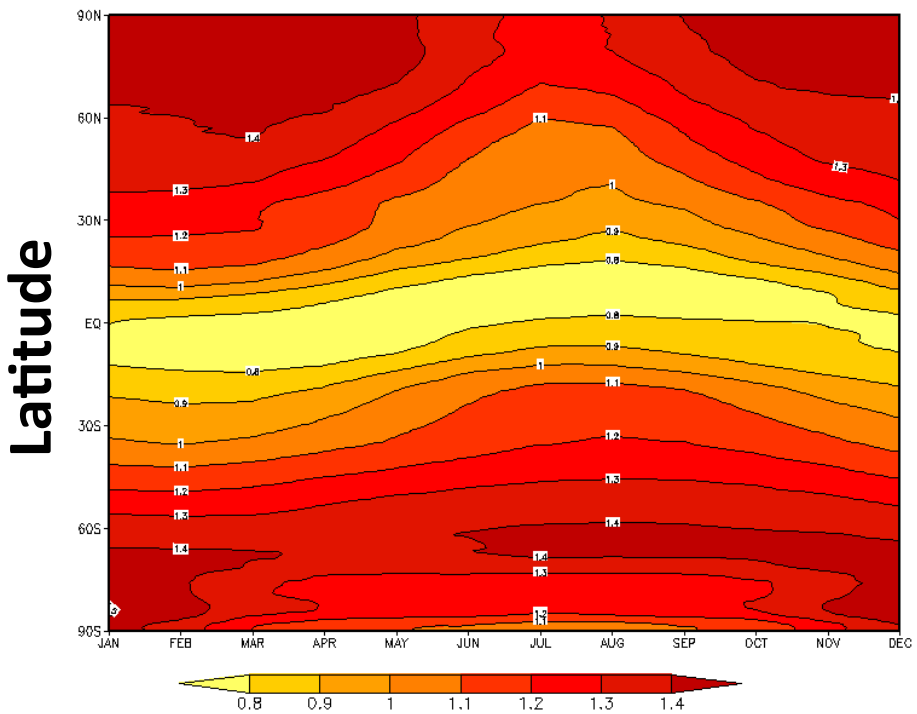
Seasonal Surface Temperature Change and CFRAM Validation

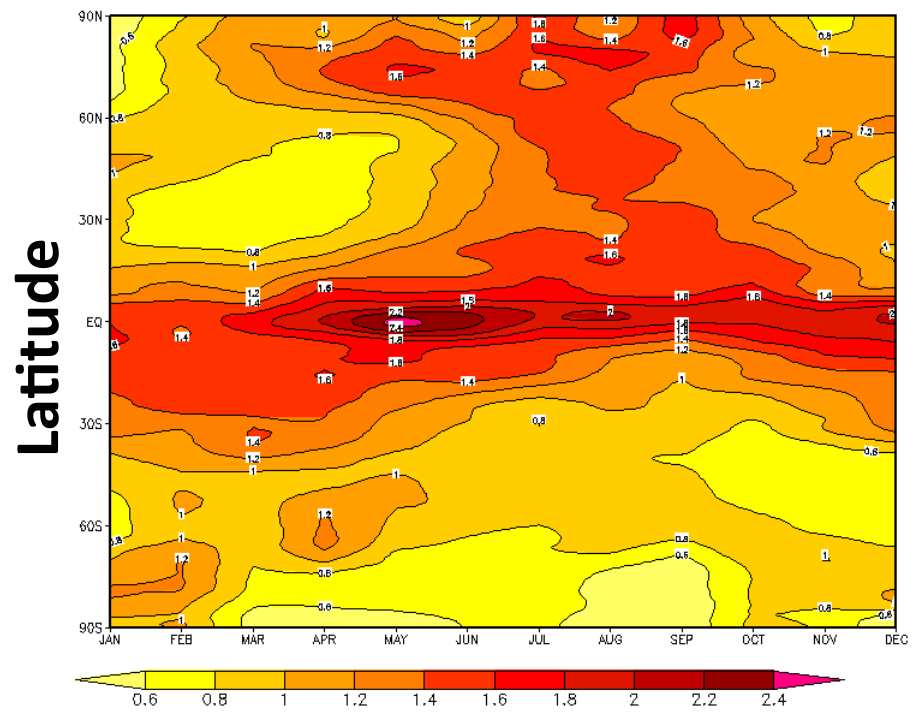
$$\Delta T_s^{tot} = \sum_n \Delta T_s^{(n)}$$



$$[\Delta T_s^{(EXT)}]$$

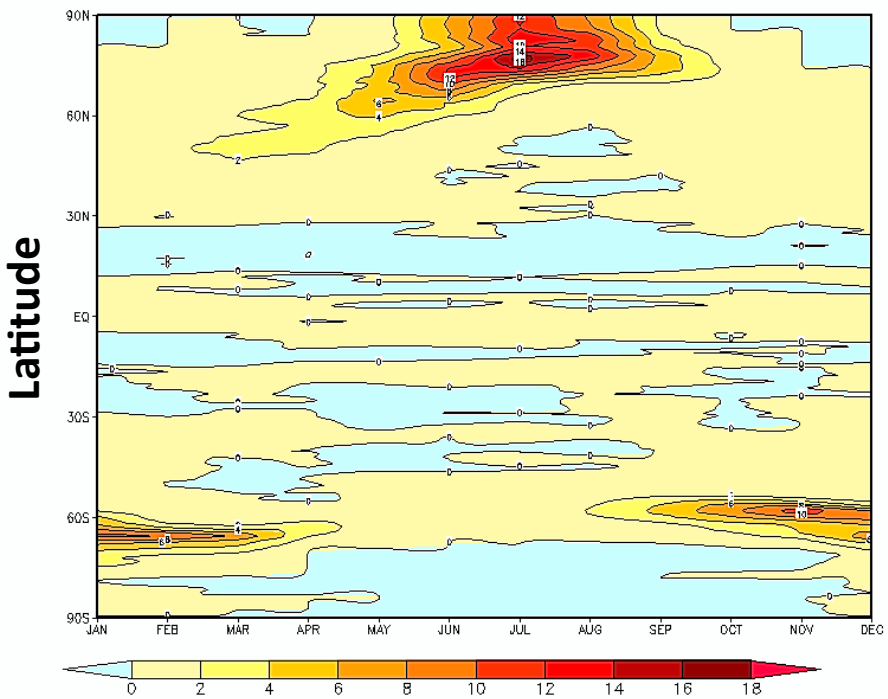
$$[\Delta T_s^{(WaterVapor)}]$$

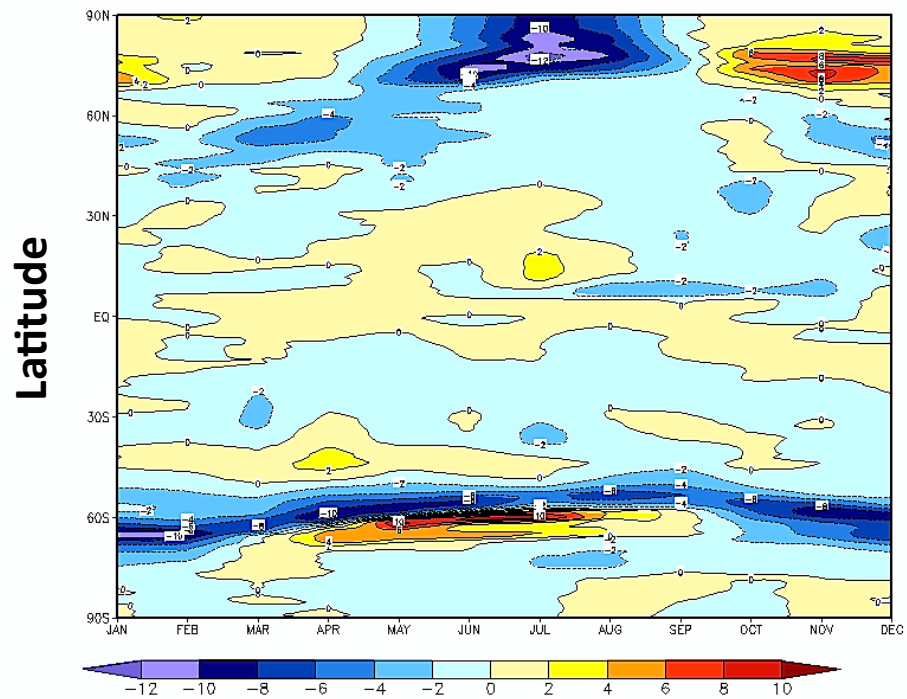




$$[\Delta T_s^{(Albedo)}]$$

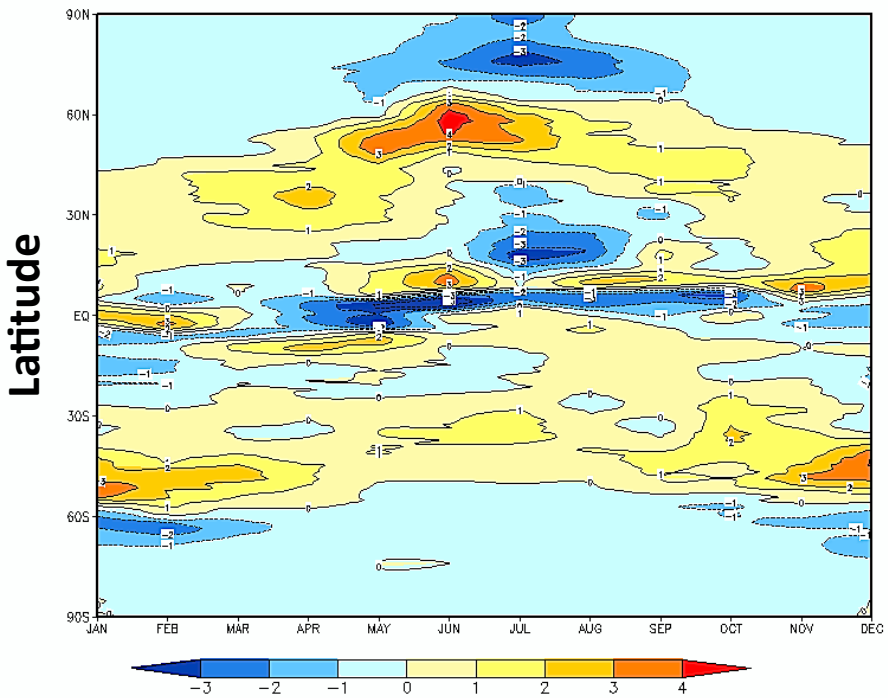
$$[\Delta T_s^{(Ocn_Dyn+Storage)}]$$

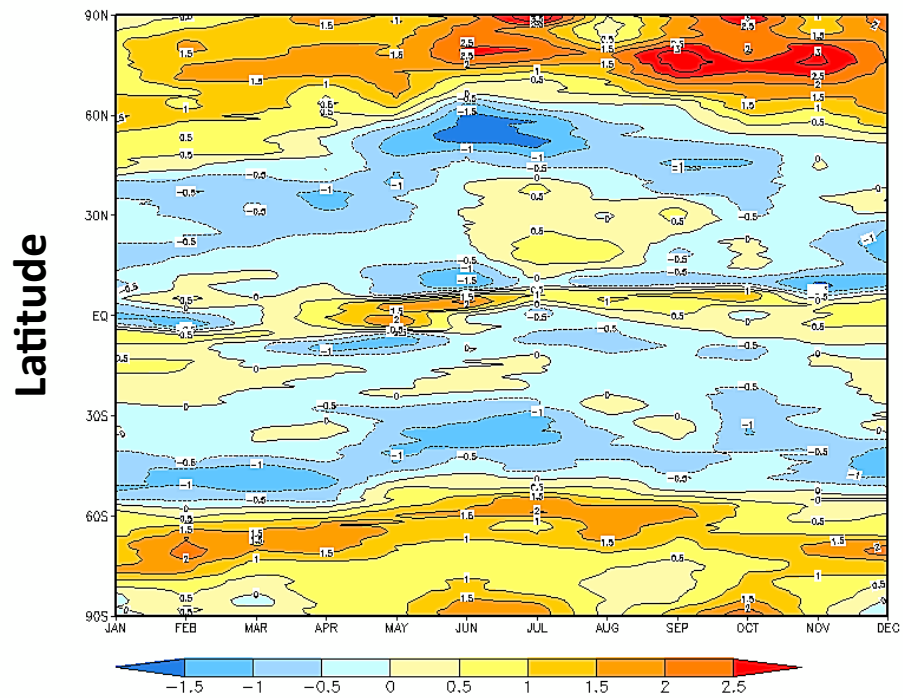




$$[\Delta T_s^{(Cloud_SW)}]$$

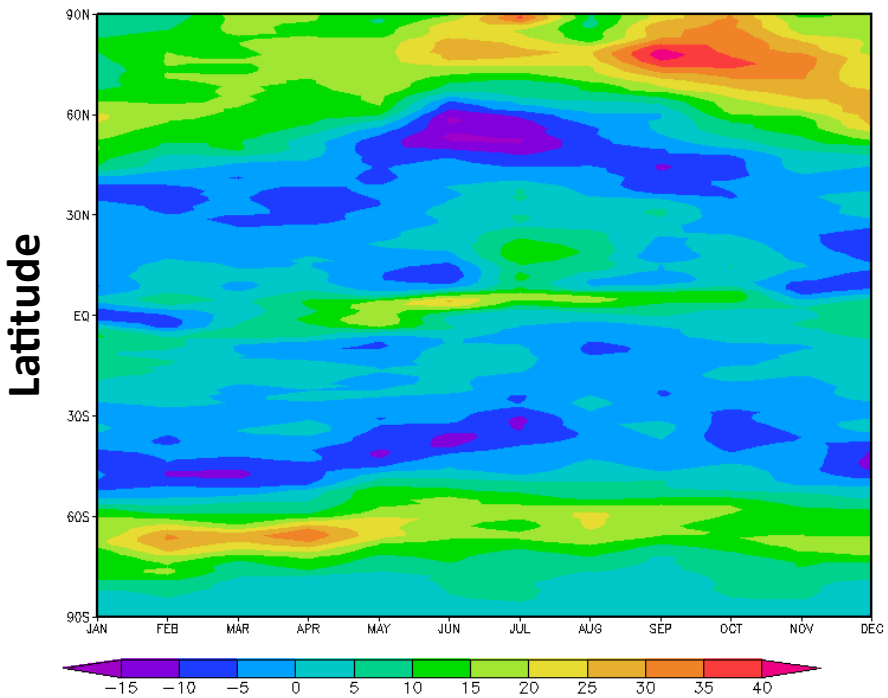
$$[\Delta T_s^{(Cloud_LW)}]$$

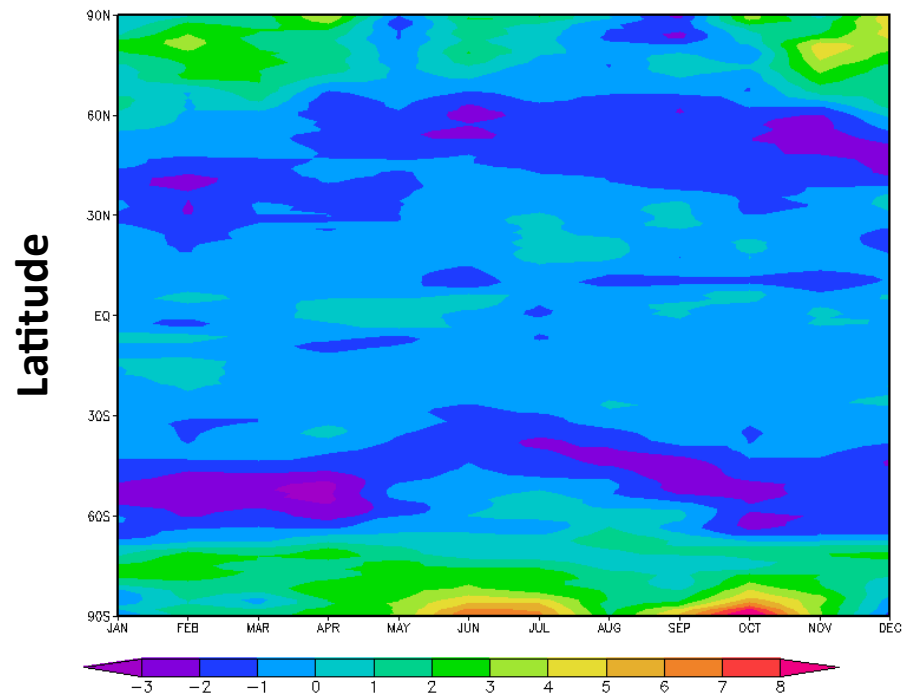




$$[\Delta Cld_LWP]$$

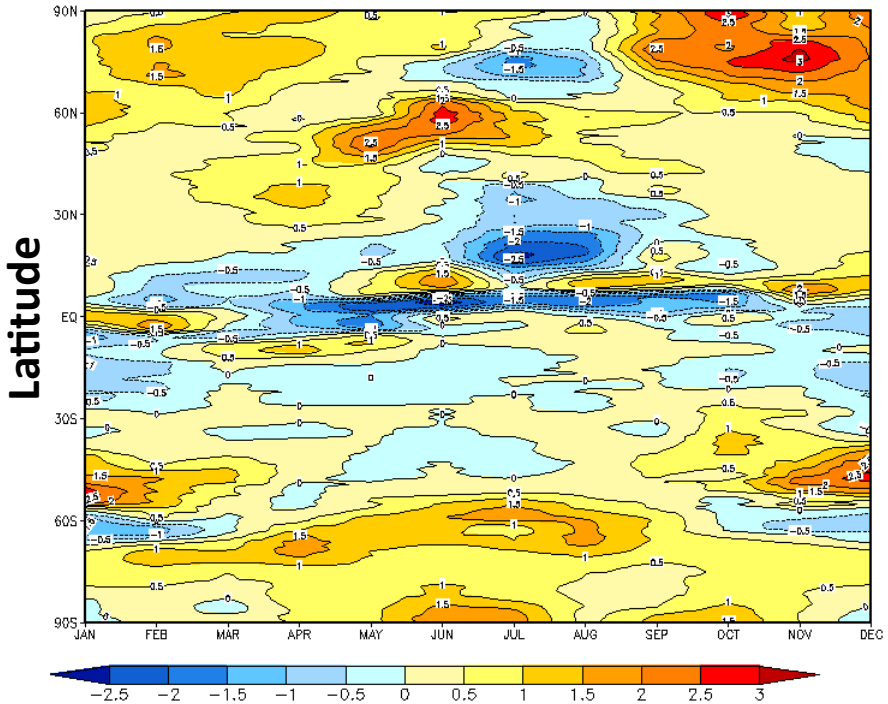
$$[\Delta Cld_IWP]$$

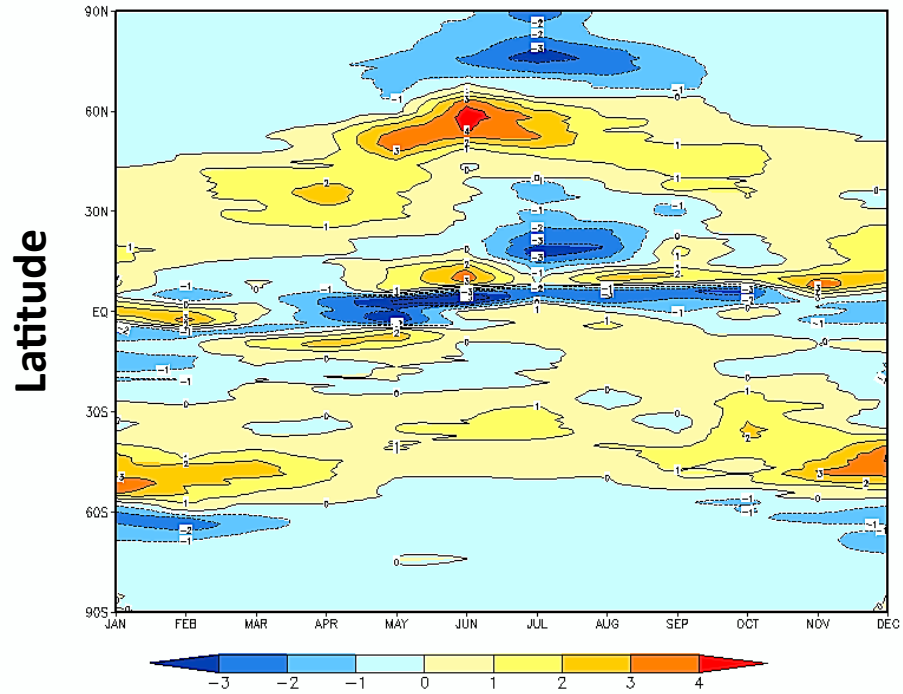




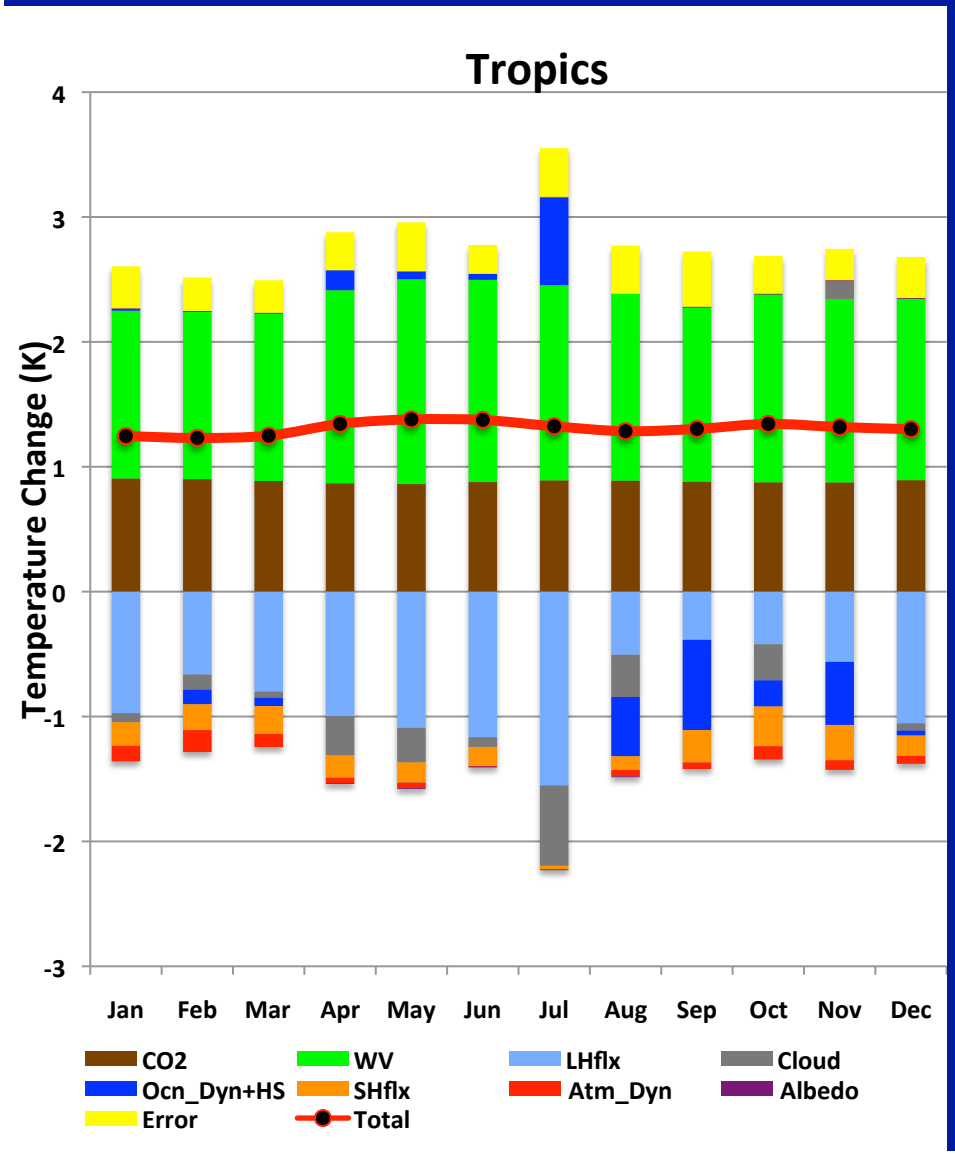
$$[\Delta T_s^{(Cloud_NET)}]$$

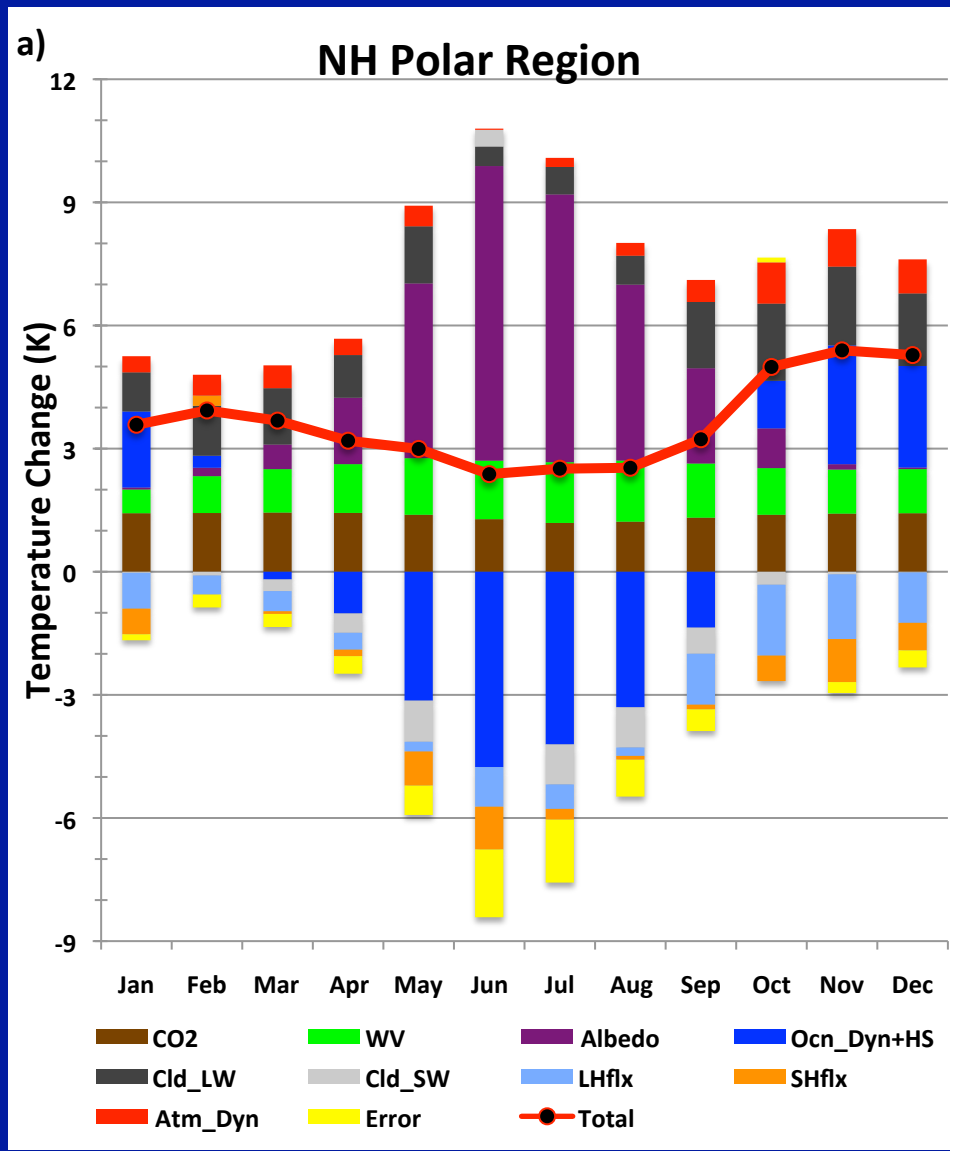
$$[\Delta T_s^{(Cloud_SW)}]$$





Tropics versus Polar Region





Tropics versus Polar Region

- Pronounced seasonality occurs in polar regions due to solar annual cycle and significant changes to the heat storage of the ocean as a result of sea ice melting.
- In tropics solar annual cycle does not vary much and no melting occurs so no seasonal variation in the tropical warming is observed.

Summary

- Interaction between SAF and ocean heat storage/dynamics feedback main cause of pronounced seasonality in polar regions and a major contributor to max polar warming in fall/winter.
- SW cloud feedback counteracts SAF in polar summer and reduces the amount of extra SW radiative flux that reaches the surface reducing ocean heat storage.
- Due to polar night and an increase in clouds, cloud feedback has a positive contribution away from summer in polar regions and is a major contributor to the max warming in fall/winter.
- Feedbacks compensate each other such as to keep the total surface warming in the tropics nearly uniform.