Arctic Amplification

Climate Dynamics

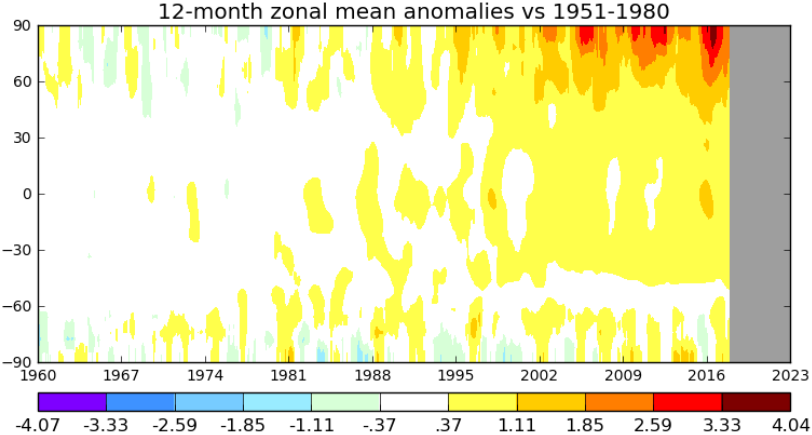
27.06.2018

UNIVERSITÄT LEIPZIG

Leipzig Institute for Meteorology

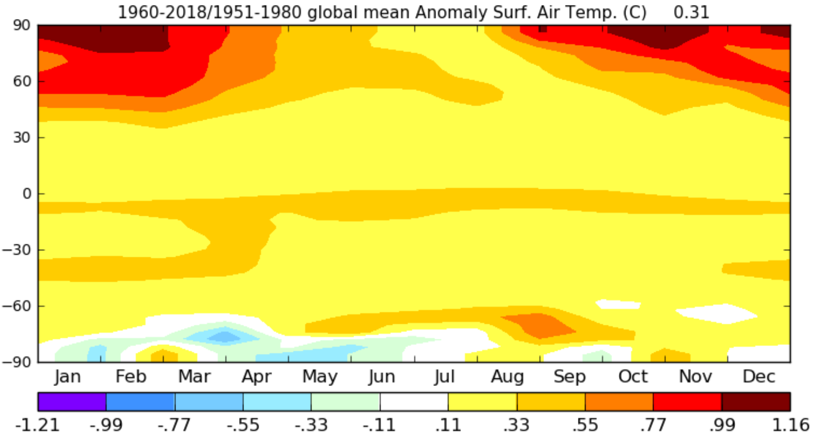
"The" Arctic Amplification Plot

Recent warming twice as strong in the Arctic as globally ⇒ Arctic Amplification



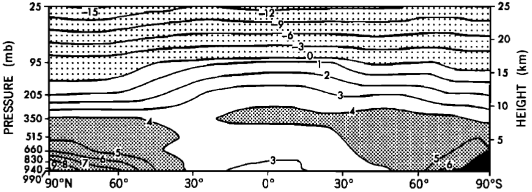
Arctic Amplification - Seasonal strength

Strongest in winter and spring



Arctic Amplification - History

- Svante Arrhenius (1896) hypothesized that changes in the concentration of carbon dioxide in Earth's atmosphere could alter surface temperatures
  → He suggested that changes would be especially large at high latitudes due to melting of seaice
- Even the first climate models show (Arctic) Polar Amplification
  (Manabe and Stouffer, 1980)
- Reduction in sea ice extend in recent decades



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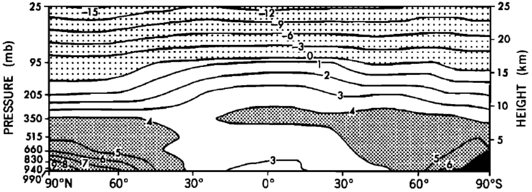
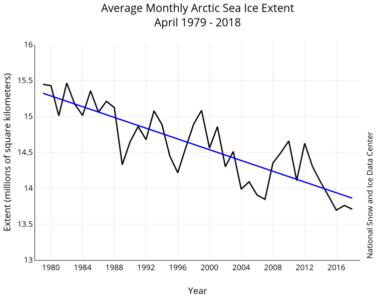
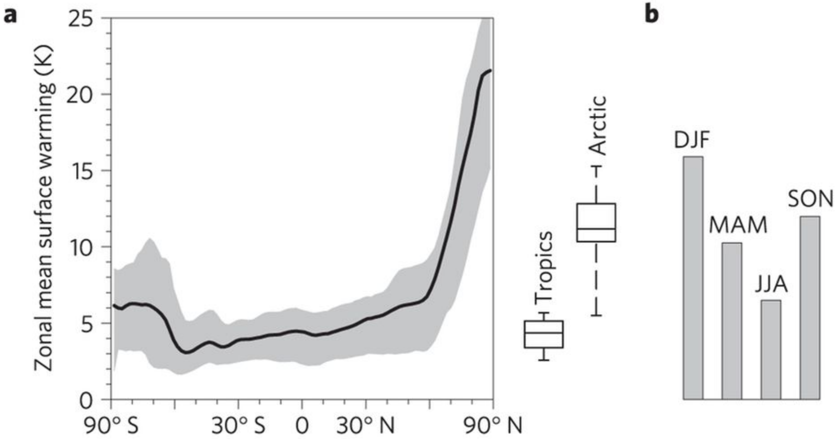




Multi model mean of $4 \times CO_2$ simulations (Pithan and Mauritsen, 2013):



Why is warming strongest in the Arctic?

Feedback mechanism in the climate system control the strength of warming/cooling due to a radiative forcing

$$\underbrace{\Delta R}_{\text{radiative imbalance}} = \underbrace{\lambda}_{\text{feedback parameter}} \overbrace{\Delta T_s}^{\text{temperature response}} + \underbrace{F}_{\text{forcing}}$$

$$\Delta T_s = -\frac{F}{\lambda}$$

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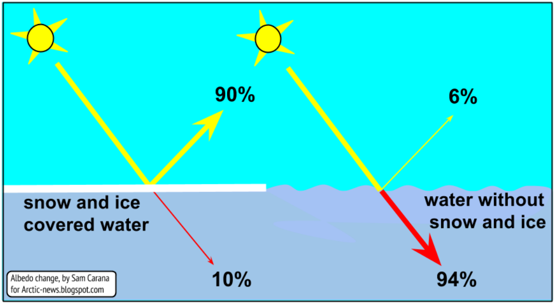
Feedbacks acting on the climate system:

- Cloud feedback
- Lapse rate feedback
- Planck Feedback
- Surface albedo feedback
- Water vapor feedback

Which of those feedbacks contributes most to Arctic Amplification?

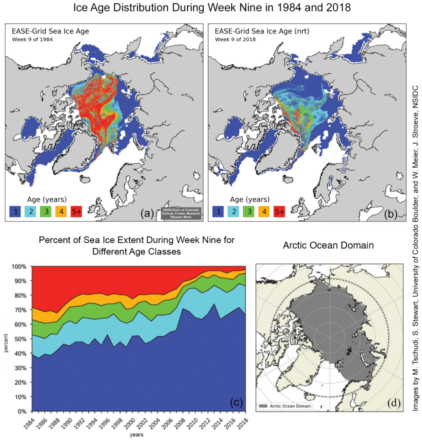
Arctic Feedbacks - Ice-Albedo Feedback

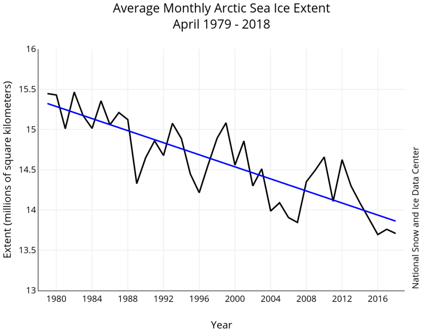
Change in the area of ice caps, glaciers, and sea ice alters the albedo



- Decreased albedo cause an increase in absorption of incoming solar radiation during summer
- Increased heat flux into the ocean during summer
- Excess heat and the missing insulation effect of the sea ice lead to warmer temperature in fall and winter

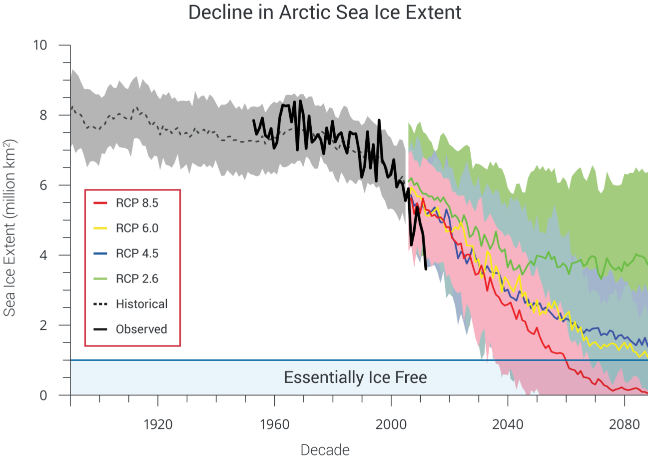
⇒ The ice-albedo is a positive feedback and acts to reinforce the initial alteration in ice area





⇒ Younger and less thicker ice is more prone to melting in summer which causes a further decrease in albedo of the Arctic ocean

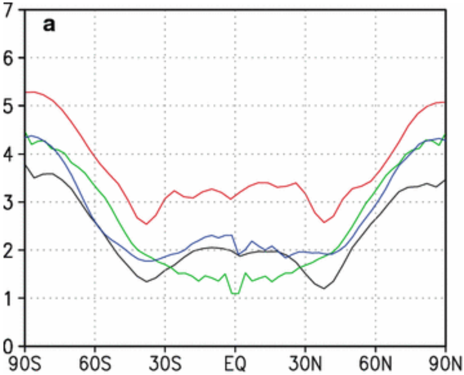
Projections of Arctic sea ice extend



⇒ Essentially ice-free in late summer by the end of the century in almost all emission scenarios

Arctic Feedbacks - Aqua Planet

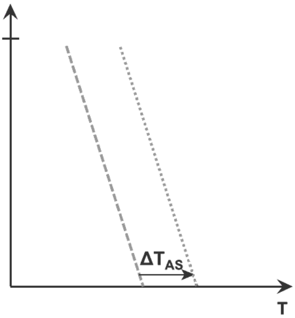
Aqua planet simulations → planet completely ocean covered, no sea ice

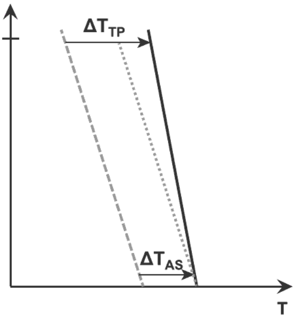


⇒ Arctic amplification does occur in models without surface albedo feedback

The total temperature feedback can be decomposed into Planck feedback and lapse-rate feedback:

- Planck feedback (λ_P) corresponds to the increase in outgoing longwave radiation caused by a vertically uniform warming (due to a ΔT_s)
- Lapse-rate feedbacks (λ_{LR}) corresponds to a warming that deviates from this vertically uniform profile





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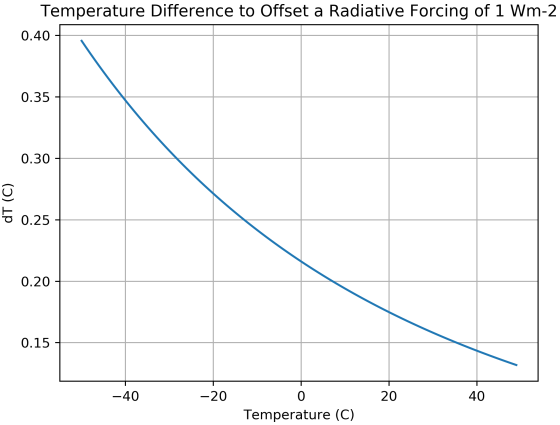
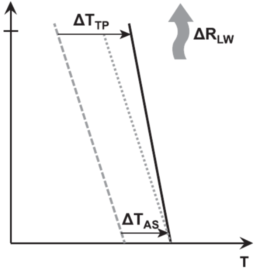


As the Arctic is colder than the tropics, the Planck feedback in itself contributes to Arctic Amplification

Lapse-rate feedbacks (λ_{LR}) corresponds to a warming that deviates from vertically uniform profile (due to a ΔT_s)

Tropics:



- Stronger warming aloft due to release of latent heat by convection
- Smaller increase in surface temperatures is required to offset a given TOA imbalance
- $\lambda_{LR} < 0$

Arctic Feedbacks - Lapse rate Feedback

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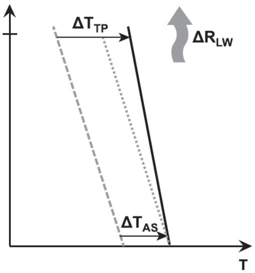

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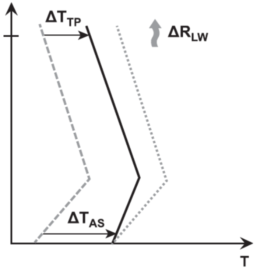
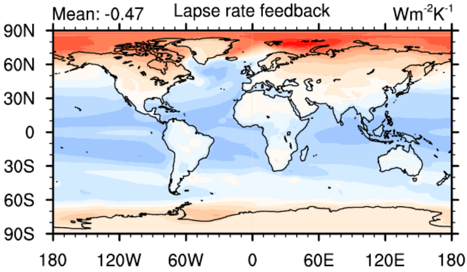
Arctic:



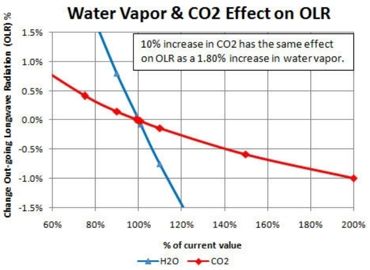
- Stronger surface warming due to stably stratified that prevents mixing
- Larger increase in surface temperatures is required to offset a given TOA imbalance
- $\lambda_{LR} > 0$

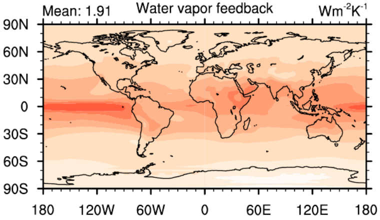
Lapse-rate feedbacks (λ_{LR}) corresponds to a warming that deviates from vertically uniform profile (due to a ΔT_s)



⇒ Positive in the Arctic (high latitudes) negative in the Tropics (low latitudes) which enhances warming in the Arctic

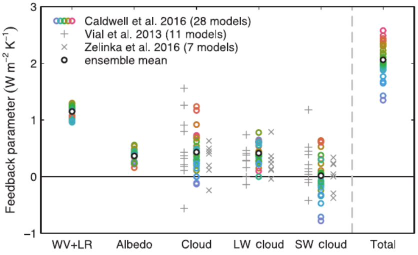
- Water vapor is a greenhouse gas $\rightarrow$ change in opacity of the clear-sky atmosphere
- Much more potent the CO_2
- Saturation water vapor pressure/content is an exponential function of T (Clausius-Clapeyron relation), so the absolute humidity of the atmosphere changes strong at warmer temperature
- Water vapor feedback stronger in the Tropics than in the Arctic due to this exponential increase
- Water vapor feedback counteracts Arctic Amplification

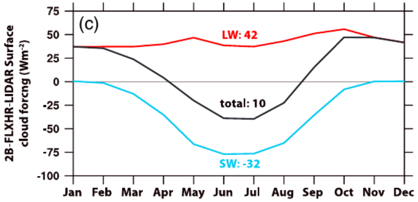




Arctic Feedbacks - Cloud Feedback

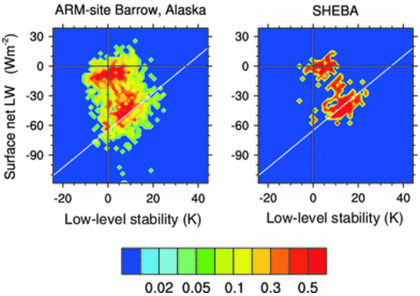
- In general, the cloud feedback is highly uncertain as many cloud processes are only insufficiently parametrized in climate models
- Sign and strength of cloud feedback depend on changes in cloud cover and cloud composition (liquid-, ice-, mixed-phase clouds)
- Globally, clouds mainly have a cooling effect as they efficiently reflect solar radiation

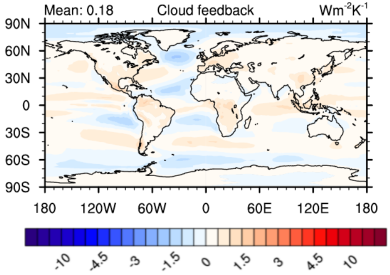




Arctic Feedbacks - Cloud Feedback

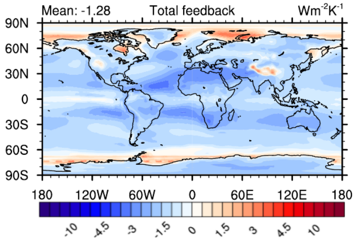
- Clouds warm the Arctic almost the whole year (due to the high surface albedo and the low solar zenith angle), except a short period in summer
- Two preferred radiative states in the Arctic: cloudy- and clear-state
- Quantification of the cloud feedback is especially complicated in the Arctic as climate models struggle to simulate low-level mixed phase cloud and therefore also the two radiative states
- Climate models suggest that it might not contribute the Arctic amplification, but this is uncertain





Arctic Feedbacks - Conclusion

- Main contributors to Arctic Amplfication are Lapse rate, Planck and Albedo feedback
- Effects of transports (atmospheric/oceanic) and clouds are rather uncertain
- Total feedback positive in the Arctic



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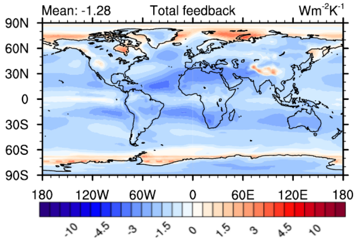

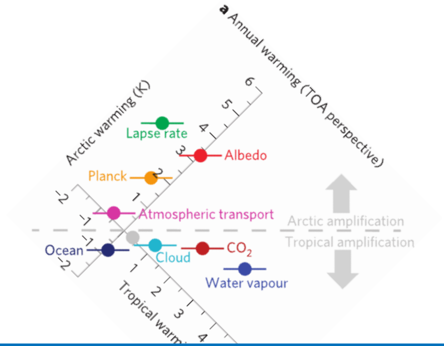

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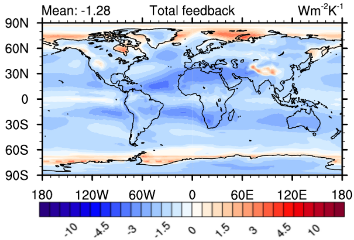

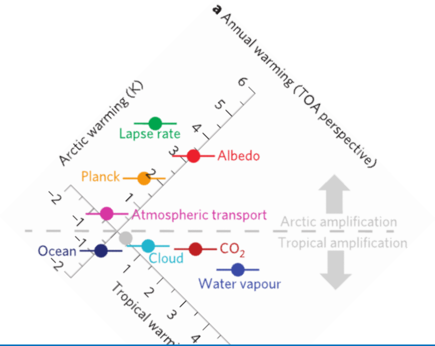

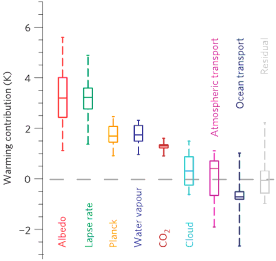

Effects of Arctic Warming

Locally (changes in cryosphere)

- Reduced sea ice (shipping, resources)
- Melting of the Greenland ice sheet (sea-level rise)
- Thawing of permafrost (release of methane)

Remote (changes in weather patterns)


Environment

Climate change is altering global air currents – increasing droughts, heatwaves and floods

Massive loops in the Arctic jetstream that have a major impact on our weather show a 'clear fingerprint of human activity'

Ian Johnston Environment Correspondent | @montaukian | Monday 27 March 2017 08:54 BST | 440 comments

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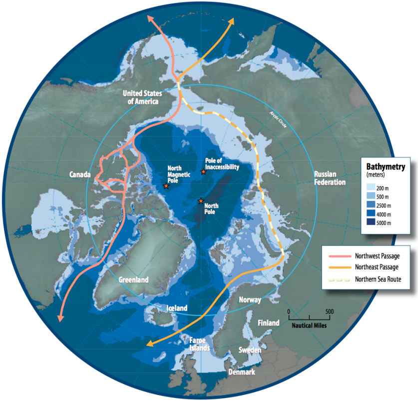
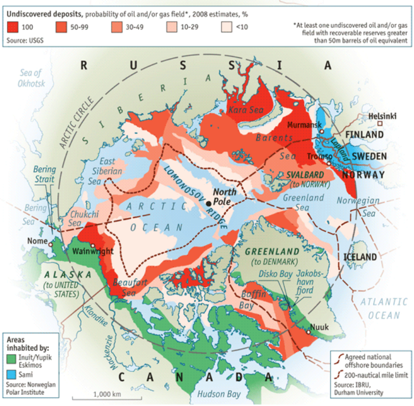
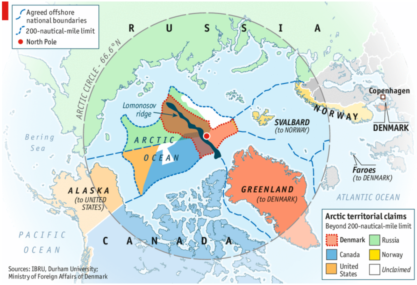
- Modification of atmospheric circulation

Effects of Arctic Warming - Reduced sea ice

- Reduction in summer sea ice up to 90% until the end of 21. century
- Opened up water will cause enhanced human activity in the Arctic
- North-West/East Passage will reduce distance to East Asia by approx. 3000 nm (5000 km) which results in a time gain of 7 days (depending on the ice conditions)
- Nevertheless, it is unclear as to whether the North-West/East Passage can be operated efficiently and economically (remoteness, weather, ice conditions, territorial claims, etc.)

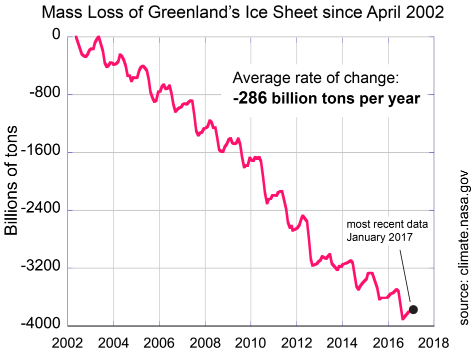






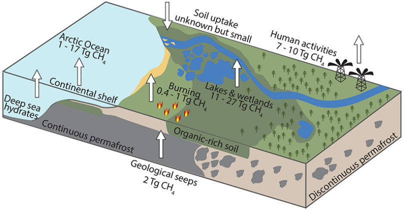
- Large oil and gas deposits in Arctic that can be exploited as sea ice retreats
- Increasing geopolitical interest in the Arctic, but disputed territorial situation
- Pollution of Arctic ecosystem due to human activity

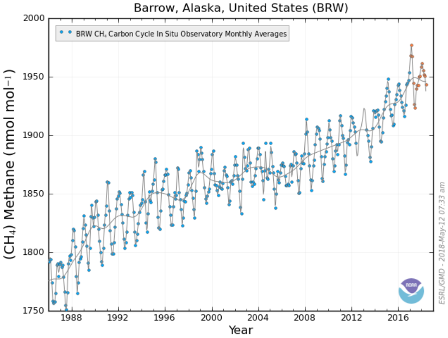
- Mass loss of Greenland ice sheet due to Arctic warming
- Increased snow fall in central Greenland due to greater moisture content of the atmosphere at warmer
- Mass gain through enhanced precipitation is more than offset by the higher velocity of glaciers
- Mass loss of approx. 4000 billion tons since 2000 which is equivalent to an sea level rise of about 12 mm (approx. 0.8 mm/y)
- If the entire 2850000 km^3 of ice were to melt, global sea levels would rise 7.2 m
- How fast this melt would eventually occur is a matter of discussion (at leat an order of multiple centuries)



Effects of Arctic Warming - Thawing of permafrost

- Soil in large areas of the Arctic perennially frozen (permafrost)
- Warming will thaw permafrost and accelerates methane release, due to both release of methane from existing stores (frozen biomass, methane-hydrates), and from methanogenesis in rotting biomass
- Methane is an extremely efficient Greenhouse gas (24 time more potent than CO_2) which will further enhance global warming (positive feedback)

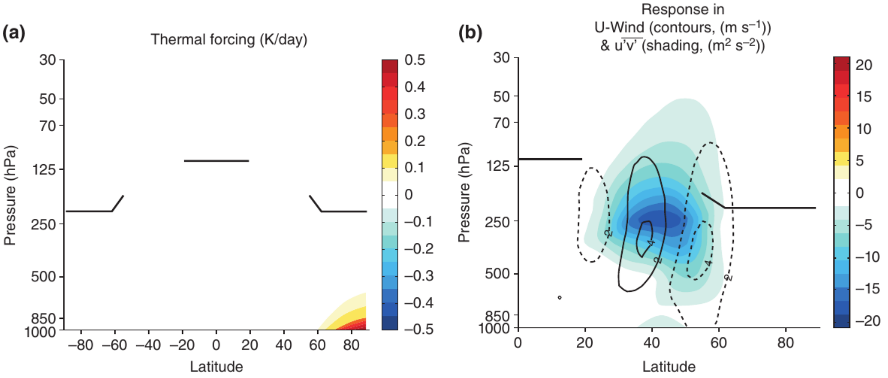




Thermal wind relationship (zonal component):

$$u_T = \frac{R}{f} \ln\left(\frac{p_0}{p_1}\right)\left(\frac{\partial T}{\partial y}\right)_p$$

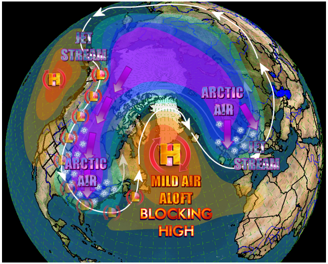
Simple atmospheric model, with thermal forcing in the Arctic:



⇒ Equatorward shift and weakening (reduced eddy momentum flux) of polar jetstream

Jet-Stream Modifications due to Arctic Amplification

- Weakening and equatorward shift of Polar Jet-Stream
- Increase of undulations (wavier), amplification of wave amplitude
  $\rightarrow$ Flag in the wind
- More blocking situations
- Intensification of meridional transports
- More extreme winters in mid-latitudes/warm air intrusions in the Arctic



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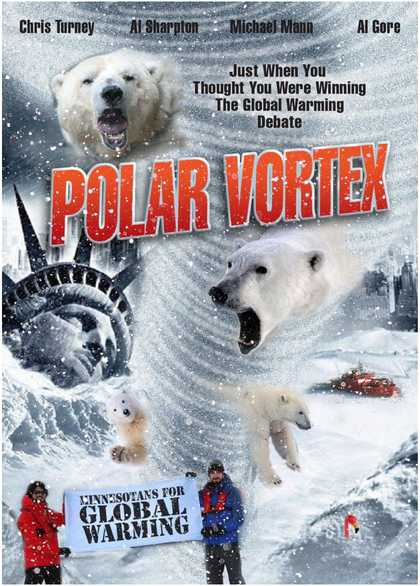

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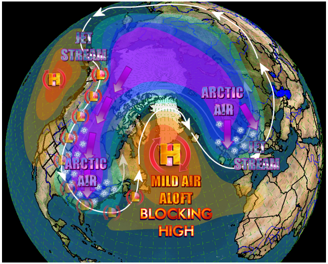
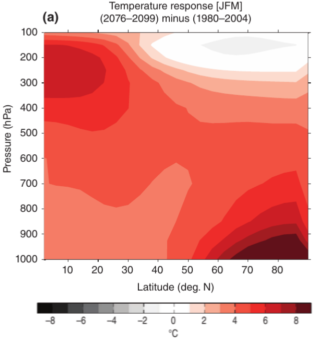


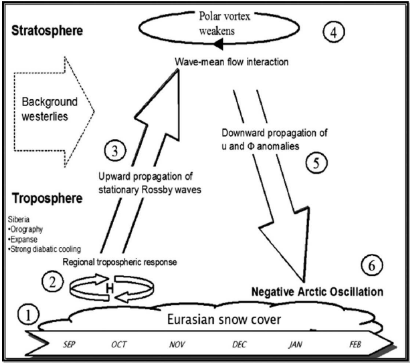


Tug-of-War (Tauziehen) in Climate Models:

- Arctic warming
  → weaker westerlies
- Tropical warming through enhanced latent heat release aloft (due to enhanced convection)
  → stronger westerlies

Jet-Stream Modifications due to Arctic Amplification

1. Increased Eurasian snow cover (in autumn)



Jet-Stream Modifications due to Arctic Amplification

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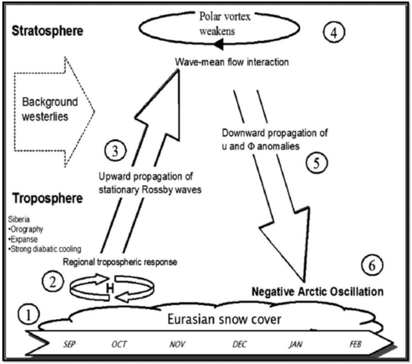

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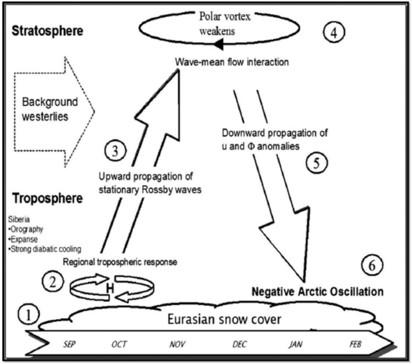
3. Increased vertical propagation of wave energy into stratosphere, wave breaking



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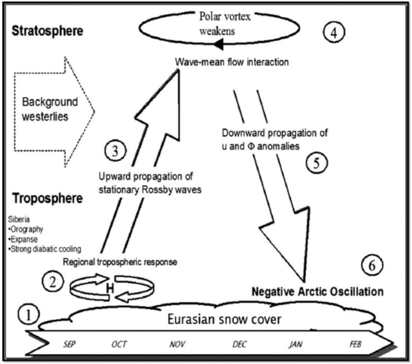

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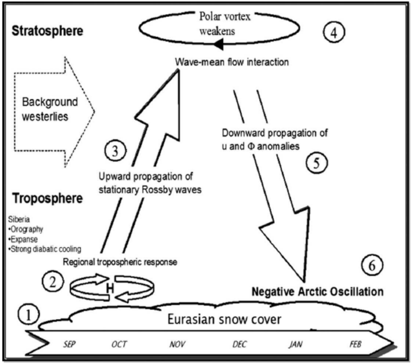

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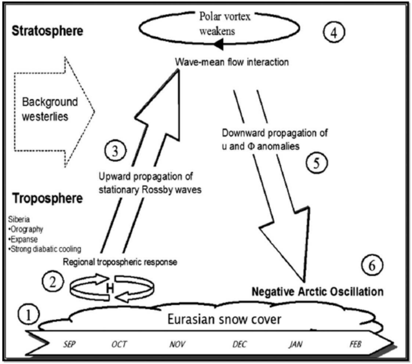
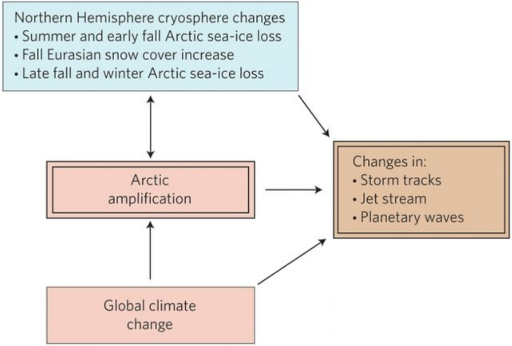
6. High pressure pauses down, stronger undulation and slowing of Polar Jet-Stream, persistent negative NAO/AO (in late winter).

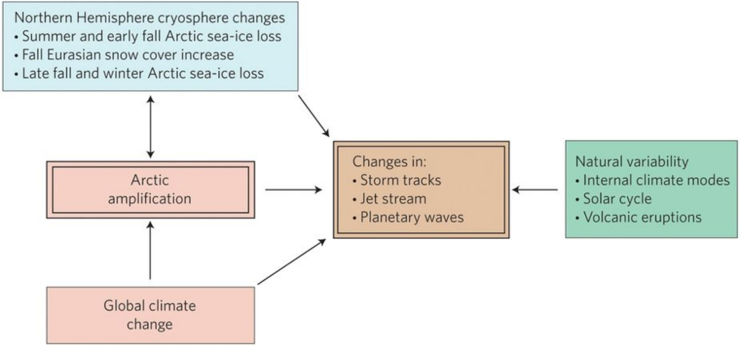


Both theories are highly disputed!



- Mid-latitude variability is always the sum of internal variability + external influences

Both theories are highly disputed!



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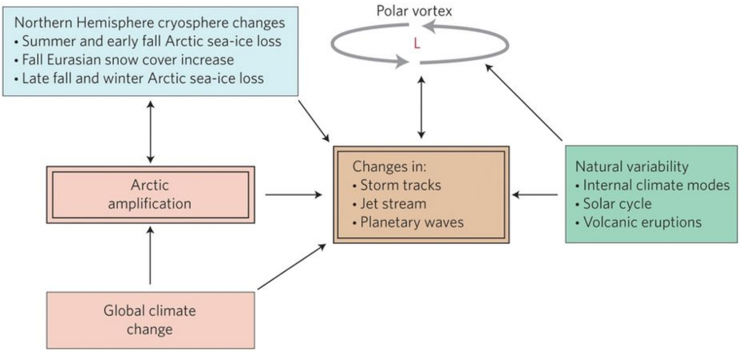

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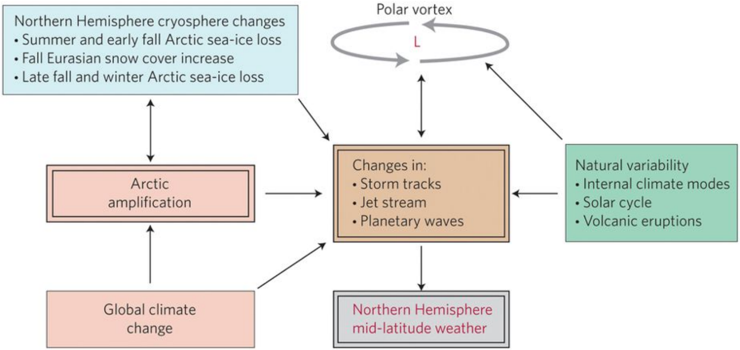

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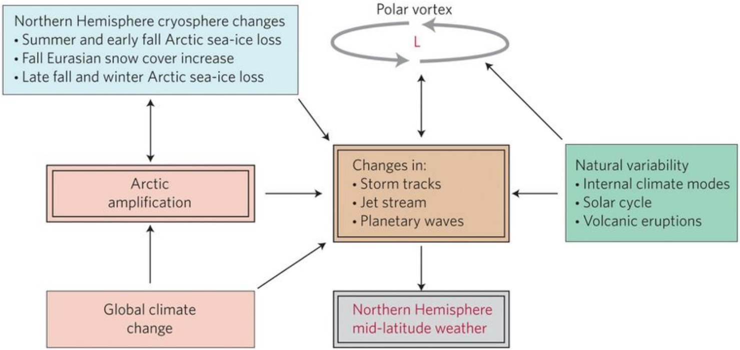

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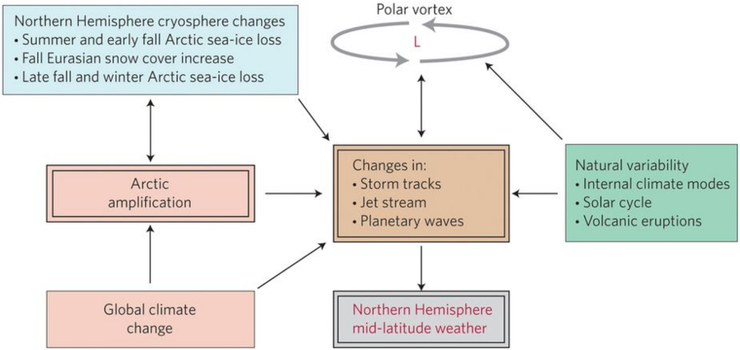

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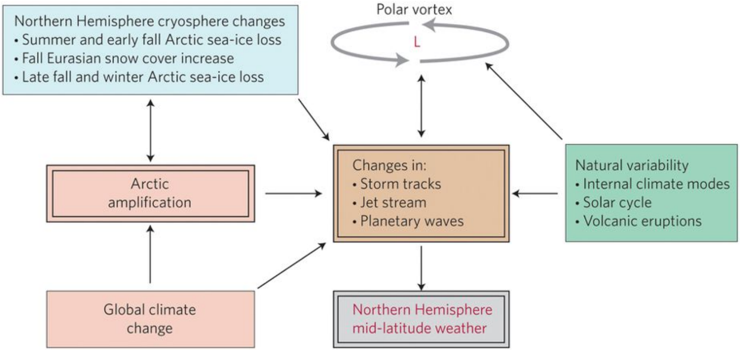

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- No consensus on whether significant effects in mid-latitude jet stream have actually been detected or not (it is nearly impossible to distinguish forced signal from background variability)
- Natural variability, observational limitations, and model shortcomings make this judgement a difficult problem
- It might also be that mid-latitudes drive the Arctic warming through oceanic/atmospheric transport (Hen or Egg?)

Conclusion

- Warming in the Arctic is twice as strong as on global average
- Several feedback mechanism are the reason for this enhanced warming
- Temperature and surface albedo feedback are the main contributors to Arctic warming
- Local and remote effects of Arctic warming