College of Natural Science and Mathematics

Cryosphere Interface

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Cryosphere encompasses sea ice, lake ice, river ice, snow-cover, glaciers, ice-caps, ice-sheets, frozen ground, permafrost

From: http://upload.wikimedia.org/wikipedia/commons/b/ba/Cryosphere_Fuller_Projection.png

Cryosphere-atmosphere interactions exist at various scales

Cryosphere affects energy budget

- by exchange of heat, moisture and matter
  - **Short-term (weather) heat, moisture major drivers**
  - **Long-term thawing permafrost releases CH_4**

  ⇒Radiation

  ⇒temperature

  ⇒feedback to more thawing
  - **Long-term changes in sea-ice extend**

  ⇒altered exchange of heat, moisture, bromine

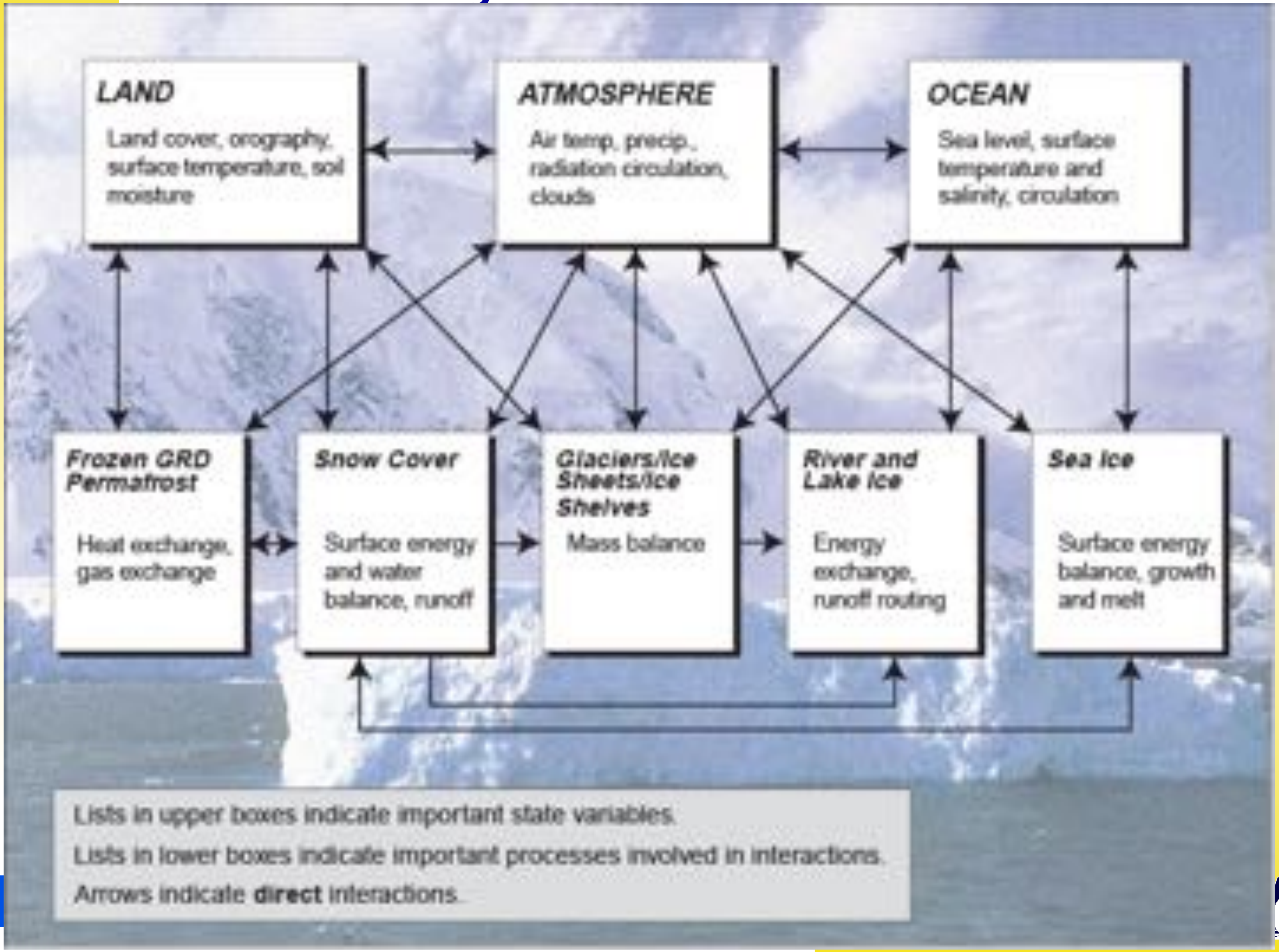
  ⇒changes in vegetation, air chemistry
- via albedo-temperature feedback
  - **Decreasing (increasing) snow-cover, glaciers, sea-ice**

  ⇒decreased (increased) albedo

  ⇒warming (cooling)

  ⇒Changes in vegetation
- Thermal properties of snow-packs change during a season
- Position/extent of sea-ice affects storms

Cryosphere is import component in the earth climate system



From: http://eospso.gsfc.nasa.gov/science_plan/Ch6.pdf

Sub-systems of cryosphere have already different time scales

- Frozen water (lakes, rivers, active layer, snow) has time-scales of hours to seasonal
  - **But freeze-up/break-up processes driven by large-scale and local weather conditions**
  - **Snow-cover has potential decadal and longer time-scale climate-system feedbacks due to impacts on temporal/spatial soil-moisture distribution**
- Sea-ice has time scales of one to several years
- Glaciers, ice-sheets, ground-ice have remained frozen for 10-10000y or longer
- Ice-cover exhibits much greater regional-scale inter-annual than hemispherical variability
- …

Time of impact of cryosphere sub-systems varies among sub-systems

- Snow-cover has greatest impact on the Earth radiative balance in April-May
- Snow-breezes (spring, fall)
- Snow-cover extent modulates the monsoon
- …

Cryosphere affects water balance

- Seasonal snowpacks affect
  - **soil moisture**
  - **depth of the active layer**
  - **river discharge (e.g. 85% of annual runoff in Colorado River basin from snowmelt)**
- Blue and green water recharge
- Collapses of the West Antarctic Ice Sheet (grounded on bedrock below sea level) has potential to raise sea level
  - **Moisture supply to the atmosphere**
- …

Data of state variables and fluxes are needed for earth system model evaluation/development

- Simulations show that one can obtained the same values of state variables with different fluxes
- Capturing the state variables are necessary conditions, capturing the fluxes are required conditions

⇒ Measure both state quantities and fluxes to close energy, and water balances

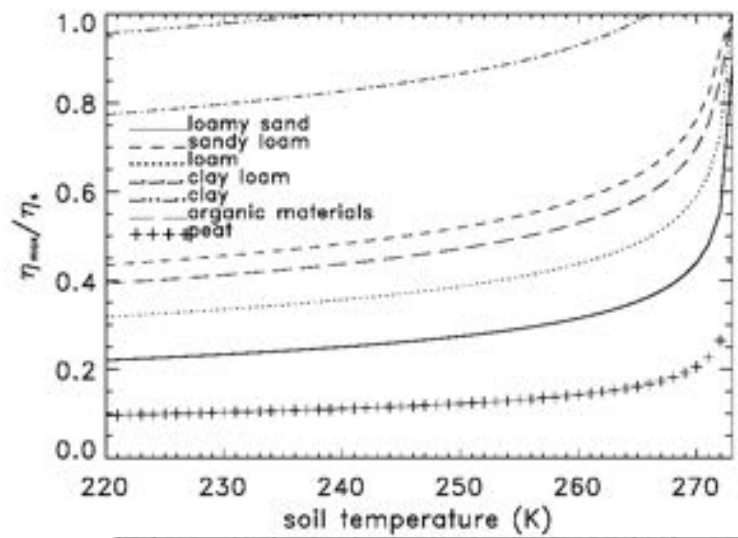
Data needs to describe cryosphere sub-systems

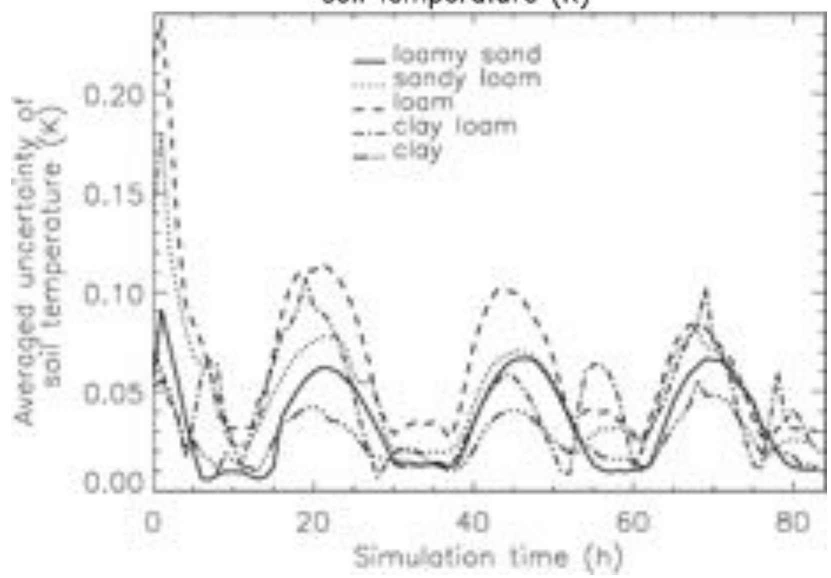
Parameter	units	needed/available accuracy	temporal resolution	spatial resolution	vertical resolution	source
Snow-cover	%, km^2	10%	d, m, y	10m-25km	N/A	ASTER, AVHRR, ETM, TMradarsat, landsat, MODIS, AMSR-E, SSM/I, ERS, JERS, SPOT
Snow-depth	m	10% (0.05m/0.2m)	d	30m-12km	0.05m	AMSR-E, SSM/I, radarsat, ERS, JERS
Snow-water equivalent	mm	10%, 2.5-25mm	d	10m-12km	0.005-0.5m	SAR, AMSR-E, SSM/I, radarsat
Soil temperature	K	0.2K	h-d	?	variable w. depth	various monitoring networks
Soil ice	-	-	-	-	-	indirectly via soil temperature
Sea-ice/glacier extent	%	7%	d, w, m	12km	N/A	AMSR-E (11), AVHRR, ASTER, MODIS, TM
Ice displacement	m	1km/300m	w	5km	N/A	MODIS, radarsat, buoys
Ice deformation	1/s	0.5%/0.1%	w	5km	N/A	MODIS, radarsat, buoys
Ice thickness distribution	m	0.505m	y	100m-1km	1-10m	SAR
Sea-ice concentration	%	<10%	d	20km	N/A	AMSR-E
Cloud-ice	-	-	d	1km	-	MODIS, aircraft
Cloud-ice effective particle radius	-	10%	d	1km		MODIS, aircraft
Ice crystal precip	-	-	-	-		ICESat, aircraft
Ice surface temperature	K	1K	d	1-100km		ASTER, AVHRR, TM, MODIS, AIRS, buoys, stations
Ice thickness distribution	1/m	10%/50%	-	-	-	sonar,radarsat
Freeze-up/break-up date	DOY	d	d	1-5km	N/A	MODIS, AMSR-E, SSM/I, stations
Soil freeze/thaw cycle	-	-	h, w, full y	-	-	ERS, JERS, radarsat, AMSR, SSM/I, stations
Fluxes	Wm^{-2}, $kg/m^2/s$	10-20% (?)	h, m, y	?	N/A	ARM, AmeriFlux, EuroFlux, stations (?)

Cryosphere relevant quantities have to be cataloged

- Various soil-vegetation models can deal with organic soil
  - ⇒ Results show different freezing/thawing behavior for organic and mineral soils
  - ⇒ Data base for spatial organic soil distribution is needed
- Sensitivity studies and Gaussian error propagation techniques show soil parameter uncertainty affects simulated permafrost temperatures, heat and water fluxes
  - ⇒ Datasets of distribution of individual soil parameters (pore-size distribution index, porosity, heat capacity, thermal diffusivity, etc.) would be even better

Modified after Mölders and Walsh (2004)





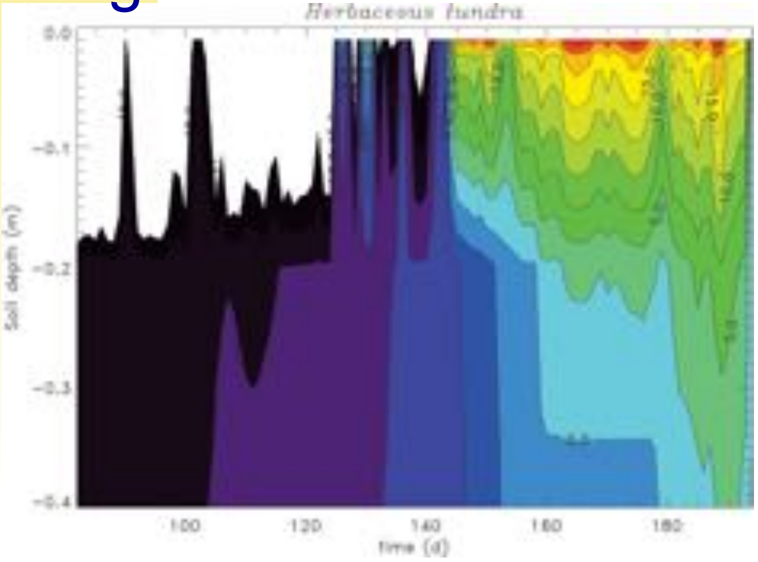
Modified after Mölders et al. (2005)

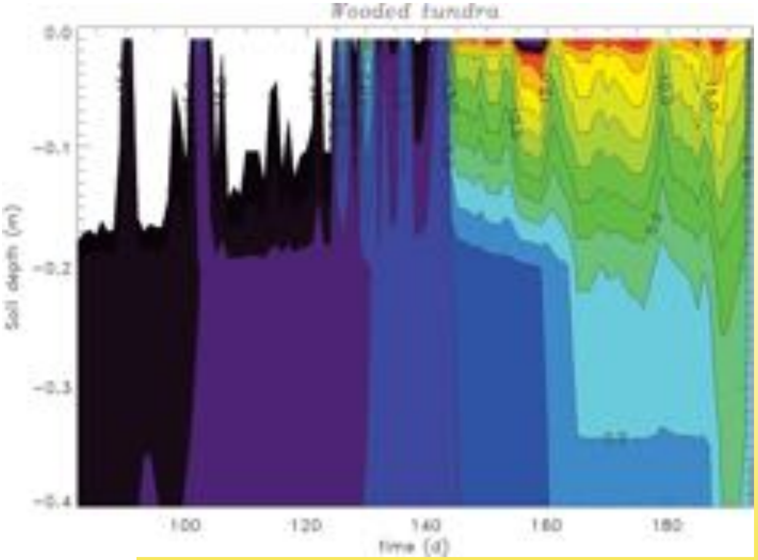
Vegetation cover also affects permafrost and the active layer

- Modeling experiment with same meteorological forcing, but different vegetation cover

⇒ vegetation type affects active layer depth, permafrost

⇒ assessment of permafrost changes needs detailed vegetation distribution data

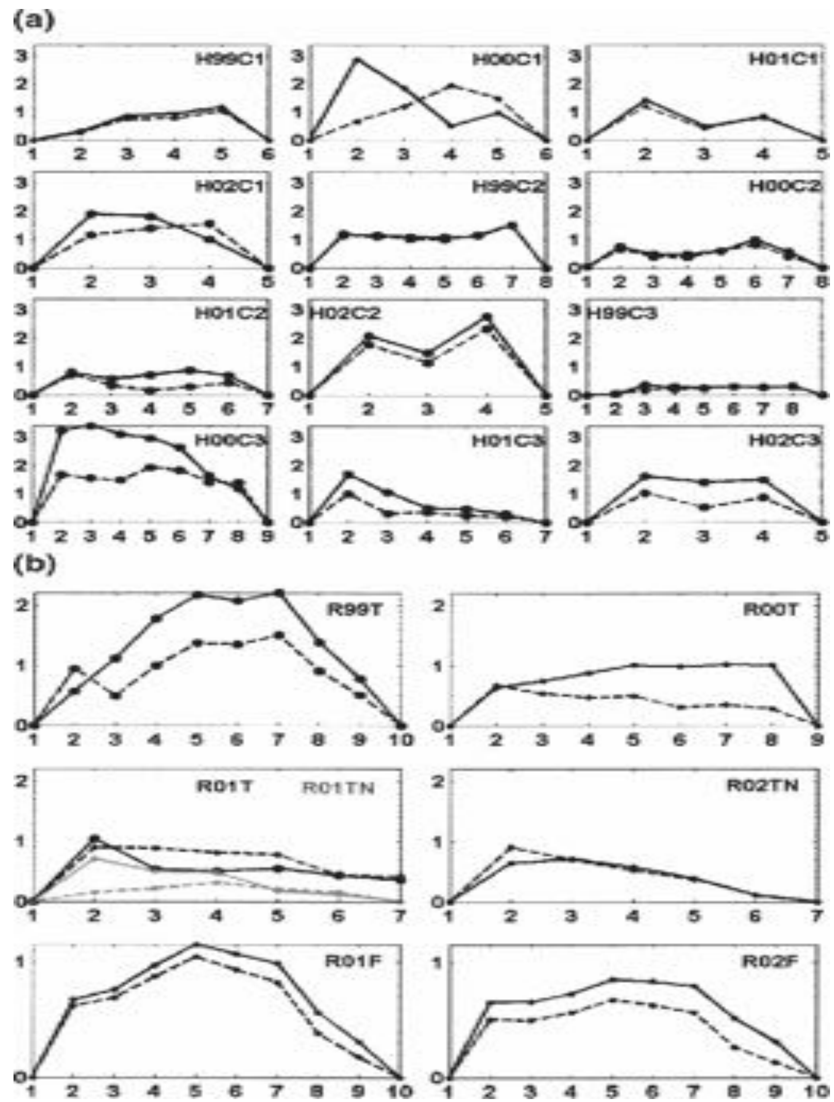




Field campaigns were suitable to develop models for understanding sub-system processes

Field campaigns

- provided insight in processes
- Allowed
  - **Model development**
  - **Model evaluation**
  - **Model intercomparison for better understanding**
  - **Identify gaps in understanding/modeling**
  - **Identify further data needs**



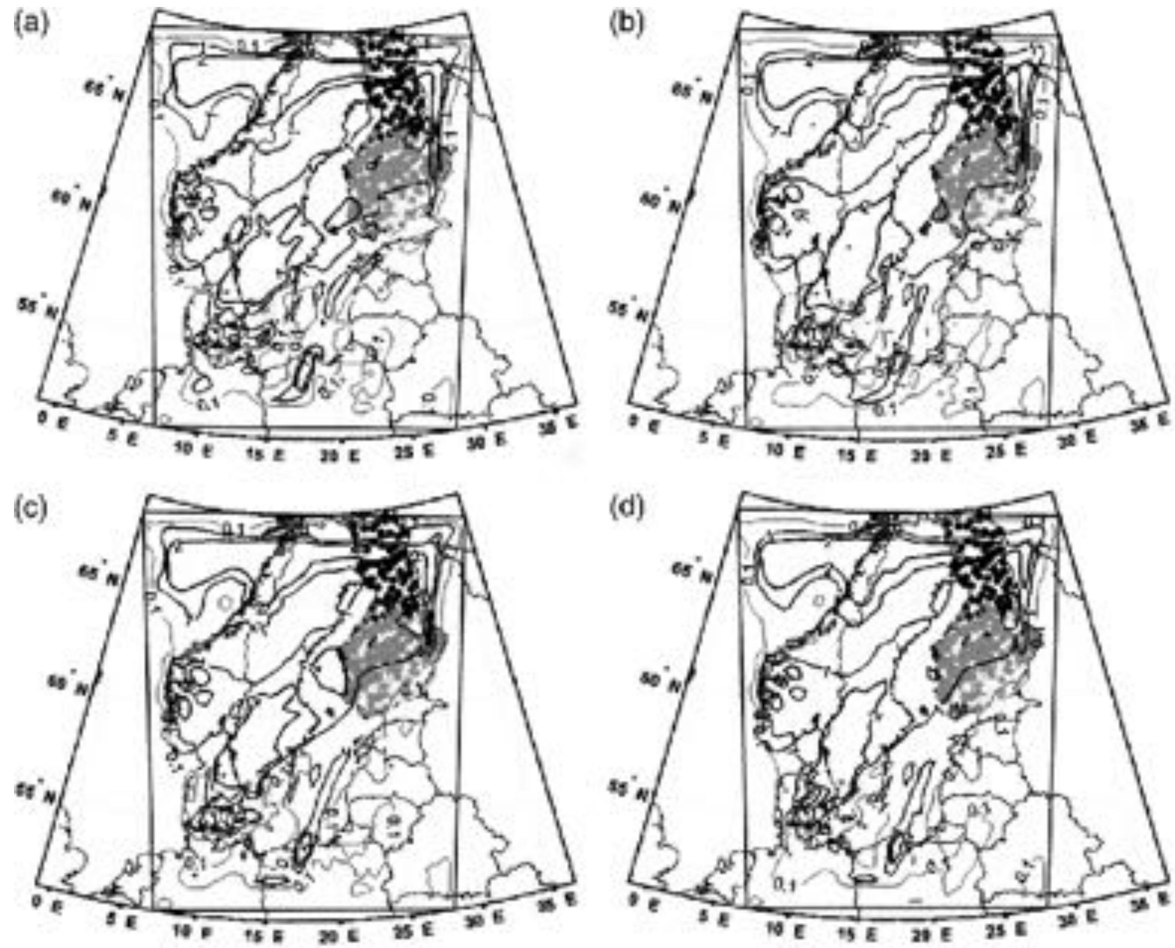
From: Narapussetty and Mölders (2006)

Soil layer vs. RMSE for 2 different parameterizations, data from ATLAS and permafrost observatory data

Routine monitoring data provided hints at possibly “missing” cryosphere processes

- MM5 predicted to high snow depth increase
- Incorrect sea-ice distribution led to too much evaporation from the Baltic Sea

⇒ Too much snowfall in Finland for all model setups



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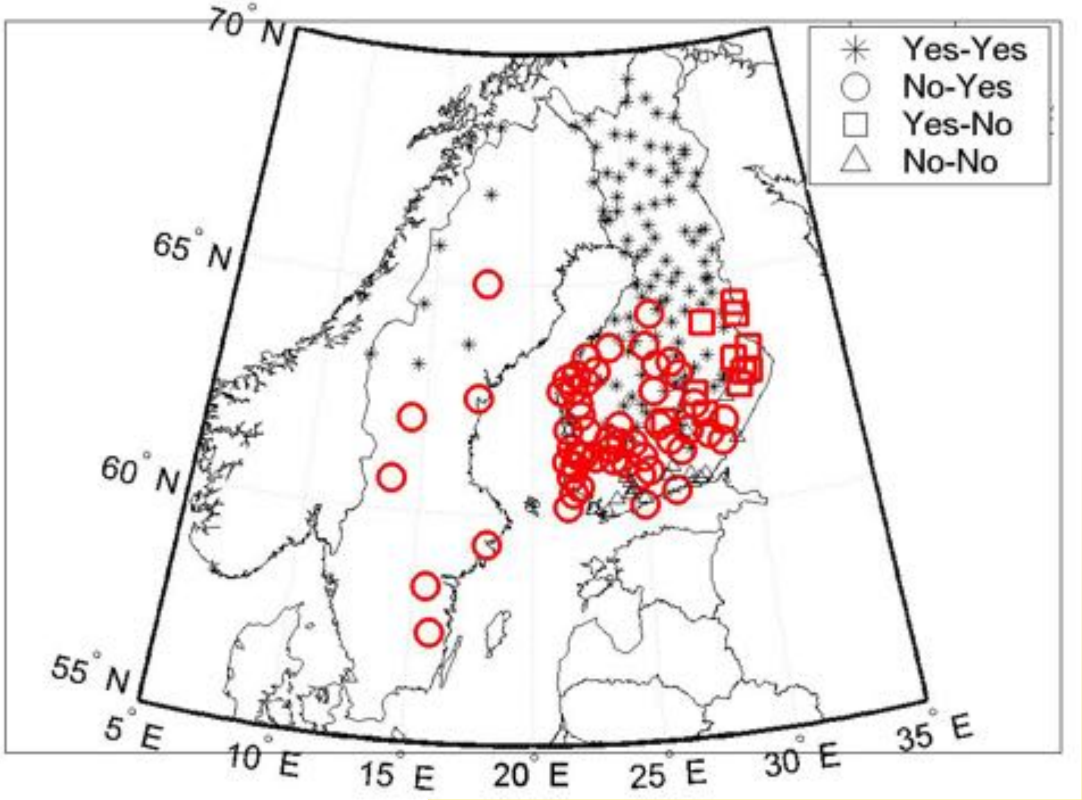
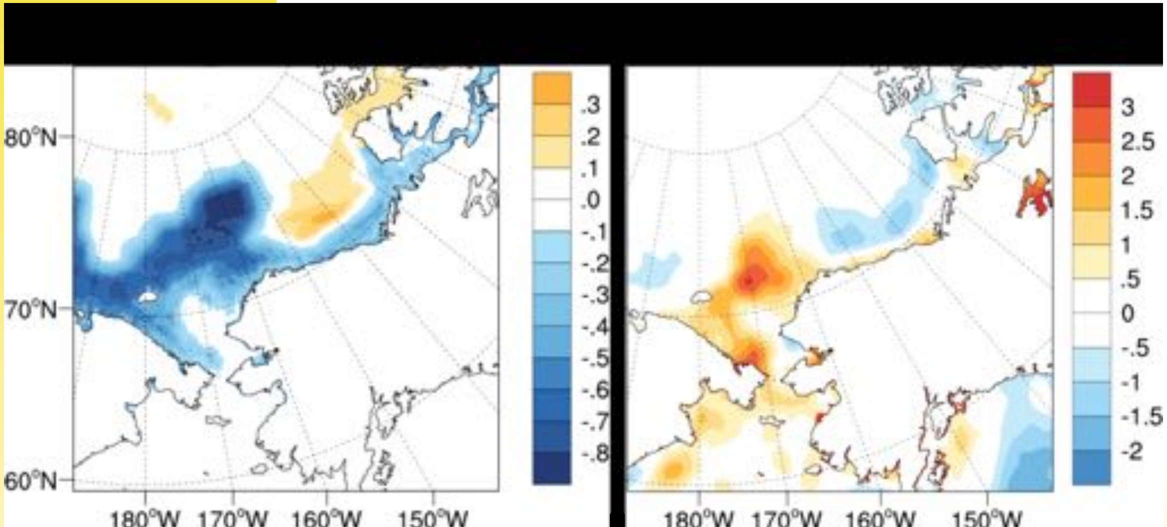


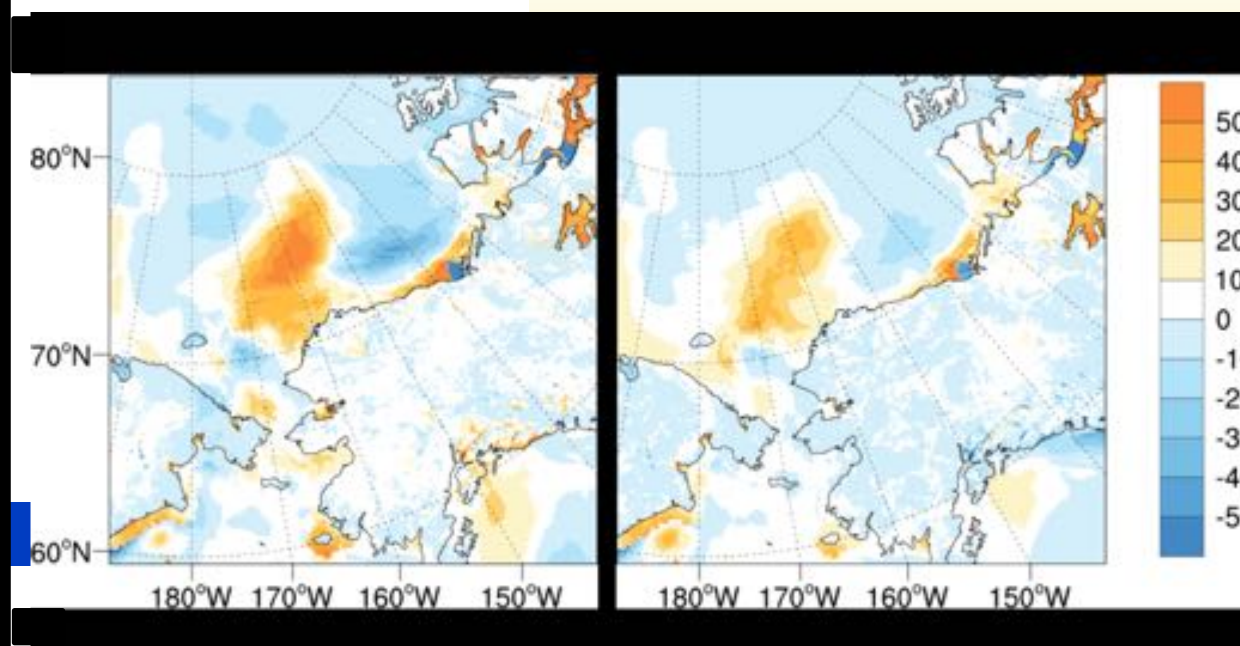
Plots for other simulations look similar

Modified after: Narapussetty and Mölders (2005)

Existence of sea-ice has consequences for SST and exchange of heat and matter

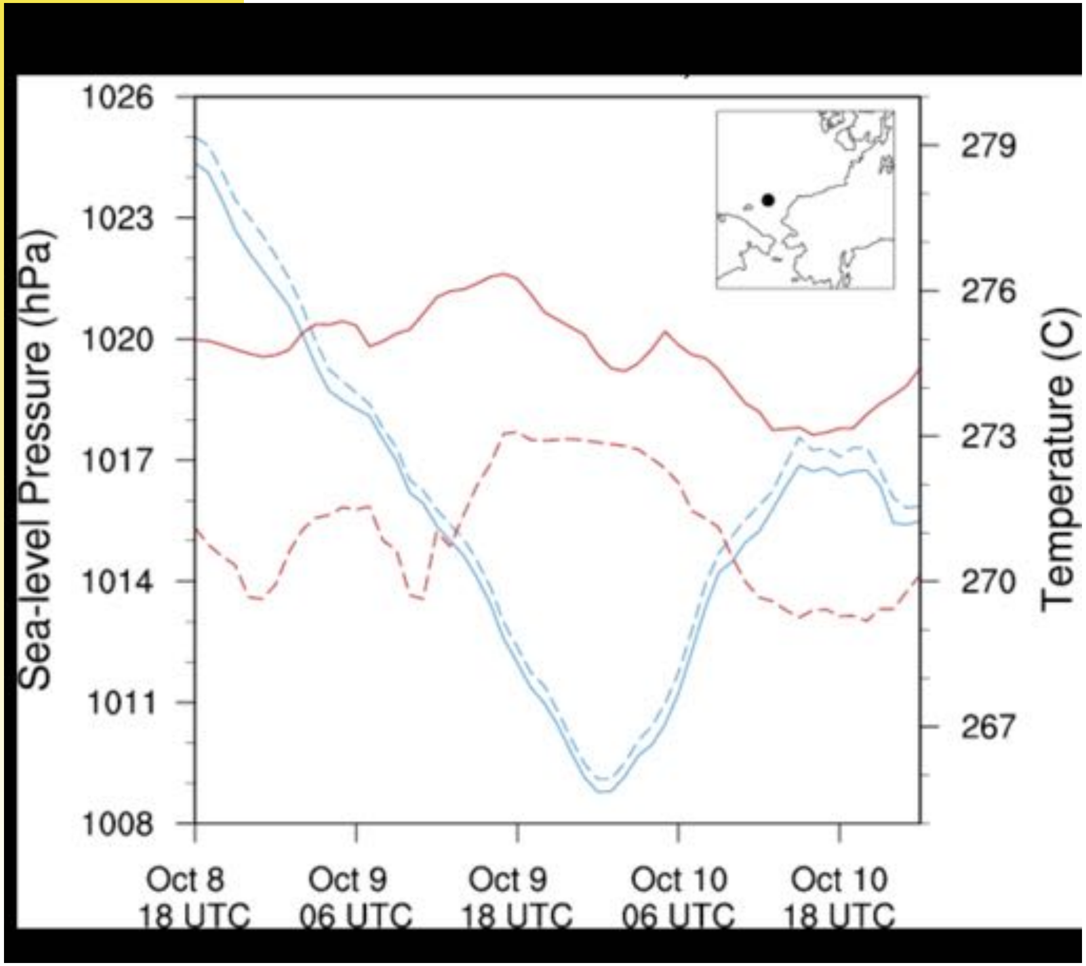


NOT_CLIM – CLIM mean difference for (left) sea-ice fraction, and (right) SST (K). From: Moreira 2011



NOT_CLIM – CLIM mean difference for Sensible (left) and latent heat (right) fluxes (W m^{-2}). From: Moreira 2011

Sea-ice distribution led to extreme polar low of 2008 => knowledge of sea-ice distribution critical to capture polar lows



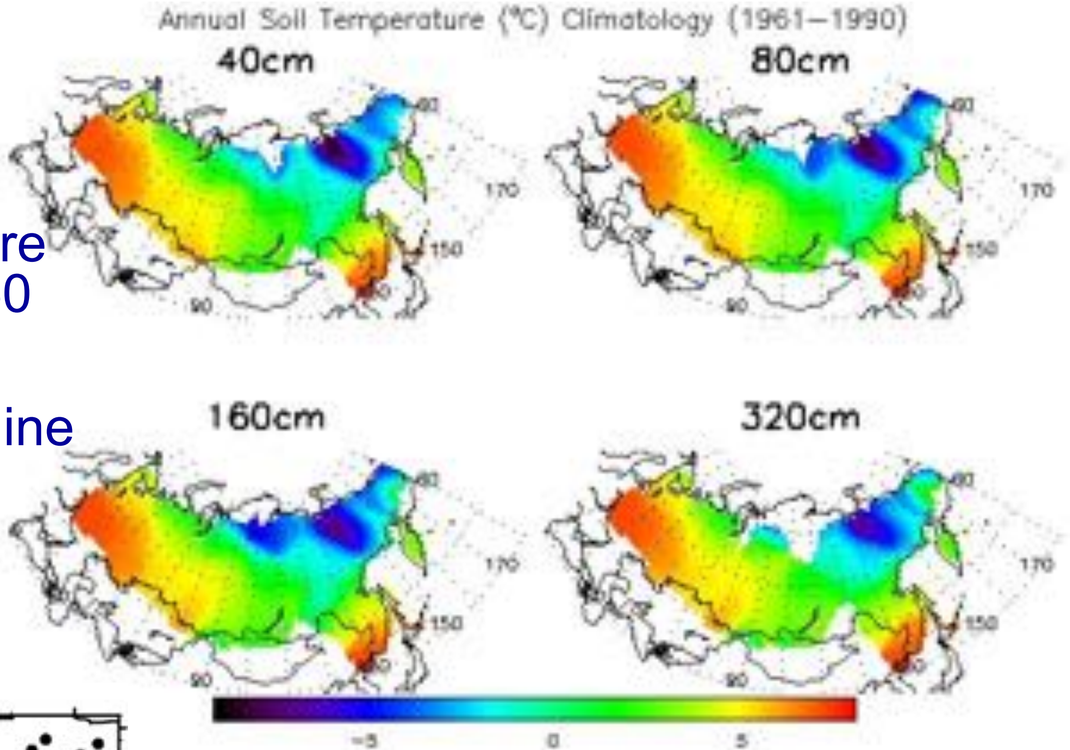
Time series of SLP (blue) and temperature (red) at 72N, 170W for NOT_CLIM (solid), CLIM (dashed) simulations. Dot indicates location relative to simulation domain. From: Moreira 2011

Climate system approach puts forward new challenges for data

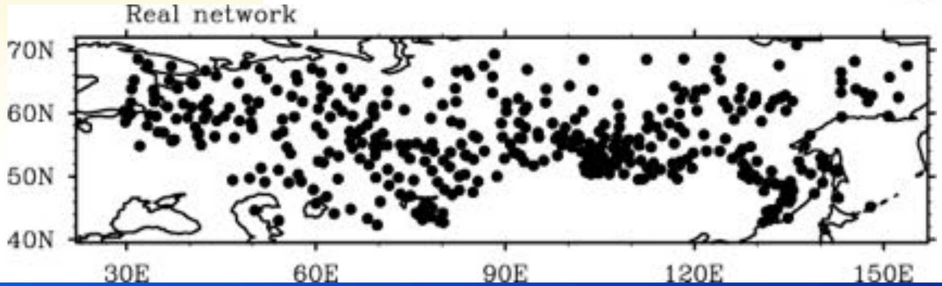
- Traditional LAOF instruments, platforms, services emphasize microscale, mesoscale and synoptic scale meteorology, air chemistry
- Climate system research needs long time-series to assess ability to capture changes
    - **Not feasible with individual field campaigns**
    - **Data must cover a large spatial scale, if not the earth**
    - **Data of more than one system may be needed**
- First steps have been made

Long time series and gridding allows understanding climatic behavior/distribution, identify changes

- In former USSR soil temperature measurements for more than 50 years
- Gridding to 2.8°x2.8° to determine soil climatologies (Zhang et al. 2005)



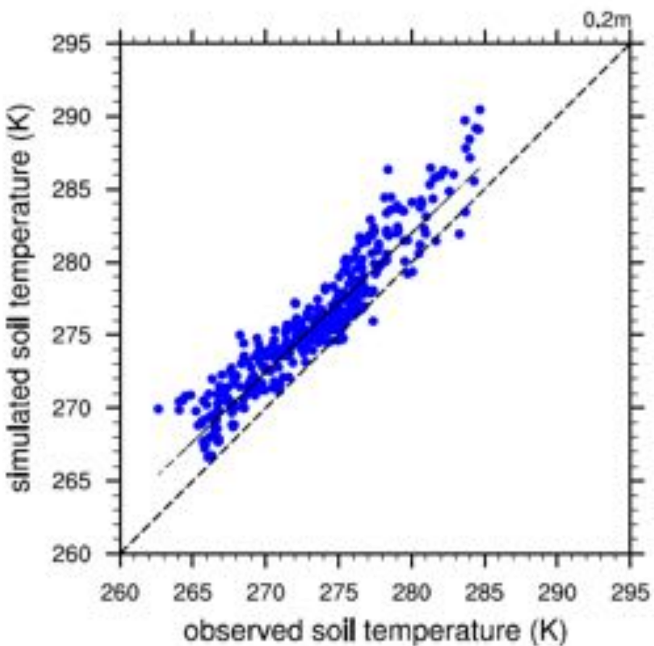
From Zhang (2005, pers. com.)

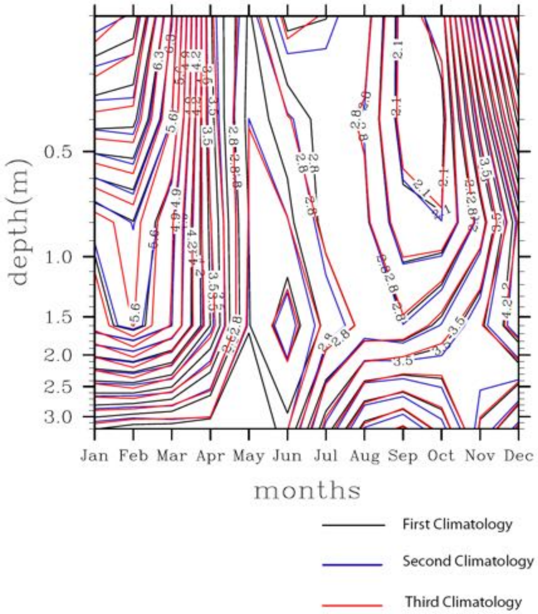


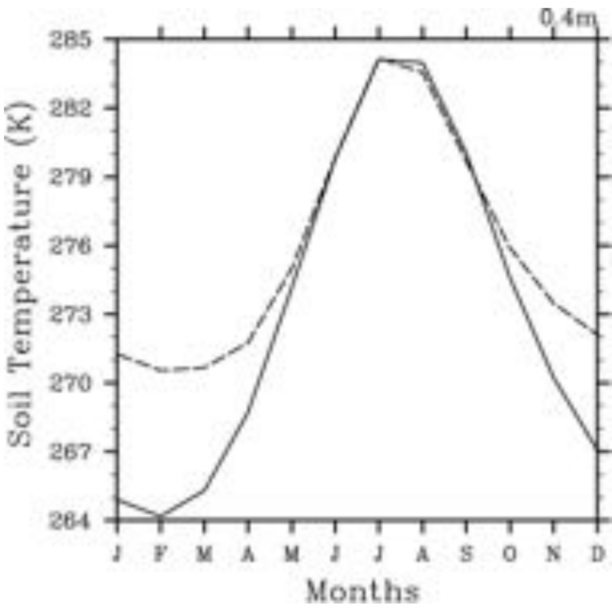
From: PaiMazumder and Mölders (2009)

Intelligent data processing procedures offer opportunity to use data for purposes other than they were originally taken for

- In former USSR soil temperature measurements for agricultural purposes
- >50y of time series
- Gridding to 2.8°x2.8° for use in climate model evaluation (Zhang et al. 2005)



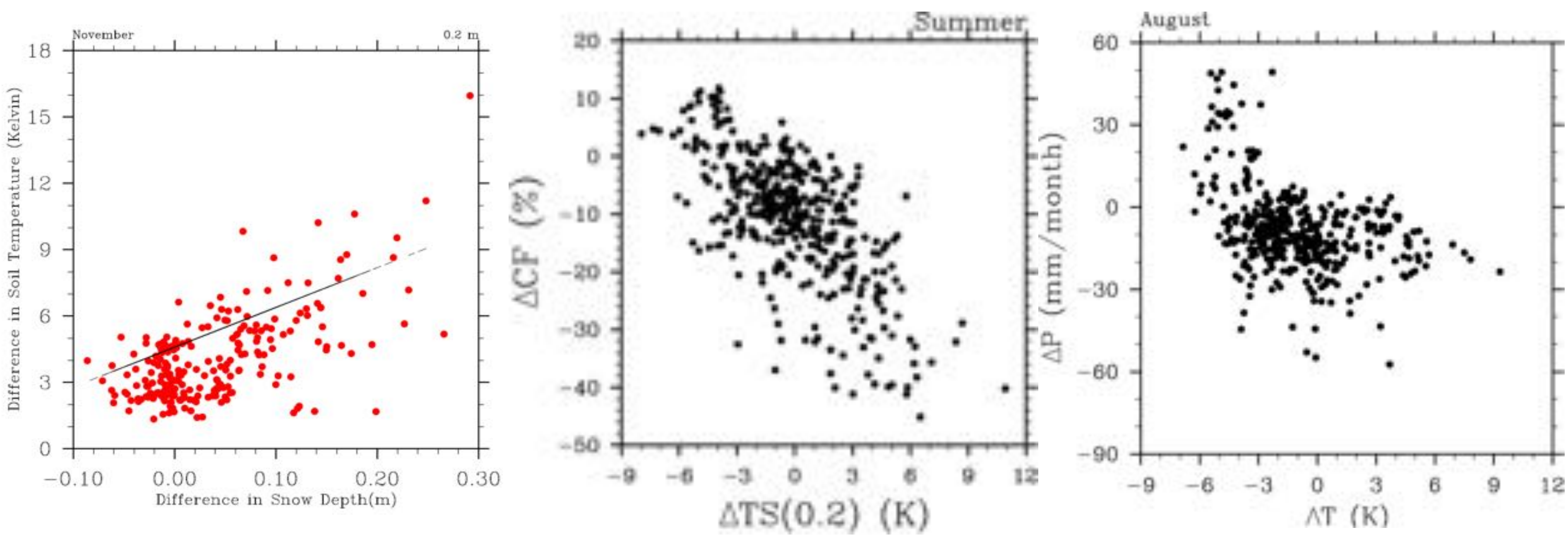




Modified after: PaiMazumder et al. (2008)

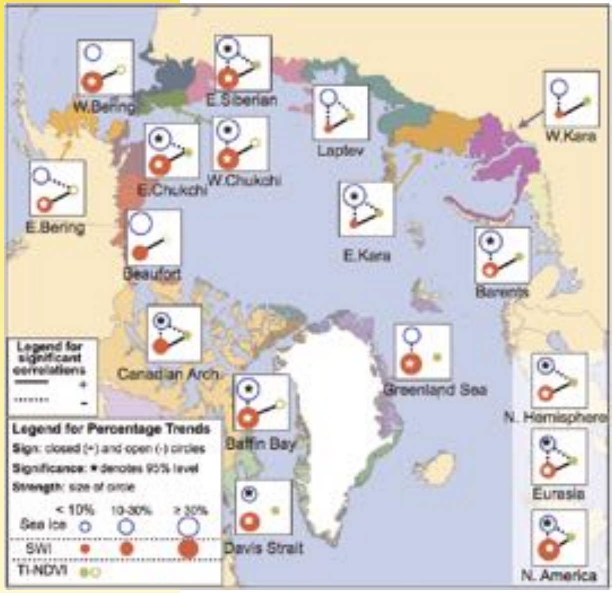
Combination of multiple datasets may lead to more than just looking at them independently or individually

- models may performed well offline, but may do differently inline
- Errors in other components may lead to errors in the quantity of interest (e.g. snow-depth. snow-temperature, soil-temperature, cloud-ice fraction, precipitation)

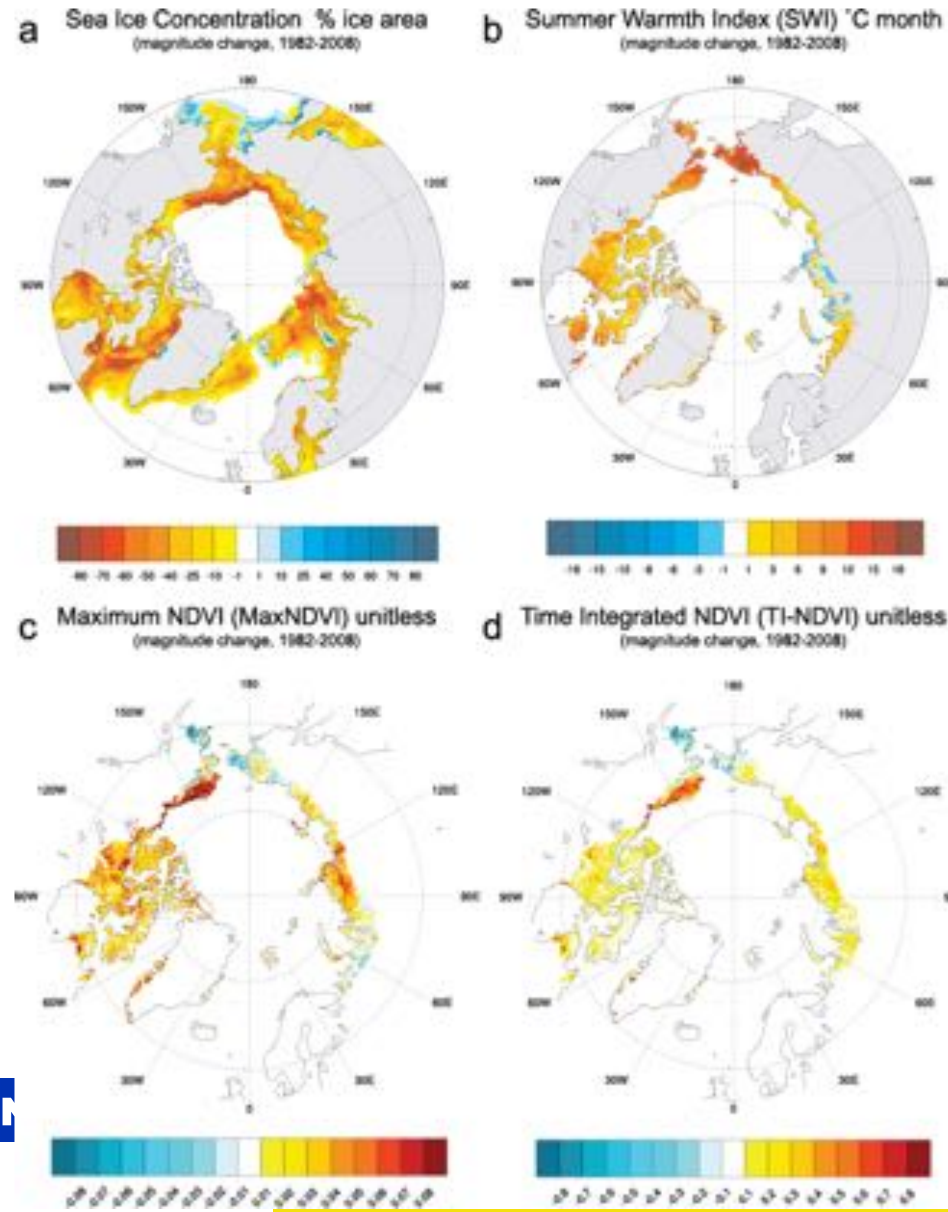


Modified after: PaiMazumder et al. (2007)

Some observed changes in a system can only be explained by changes occurring in other systems

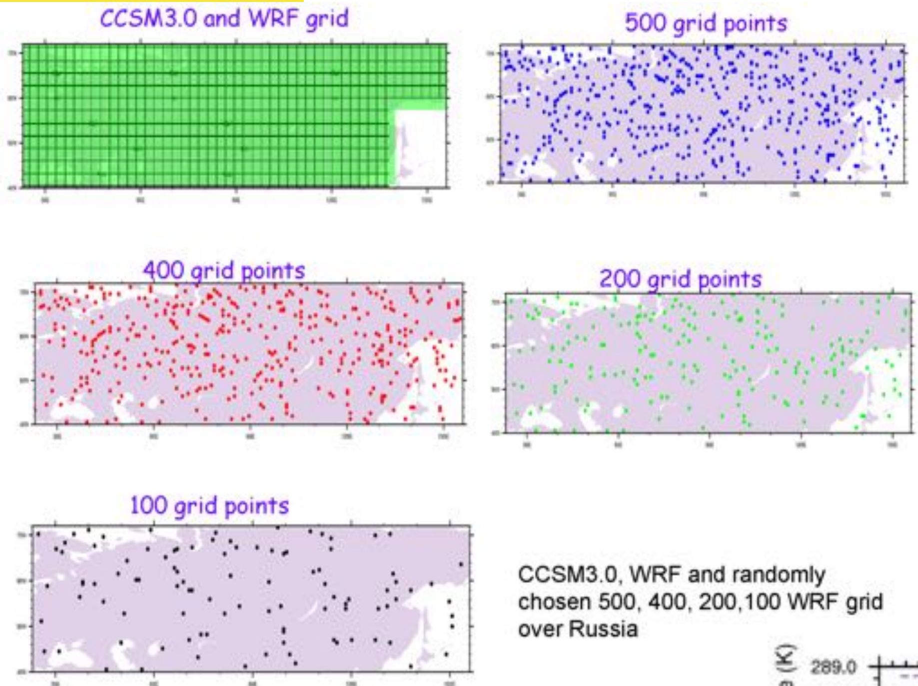


From: Bhatt et al. (2011)



Circumpolar Arctic tundra vegetation change is linked to sea-ice decline

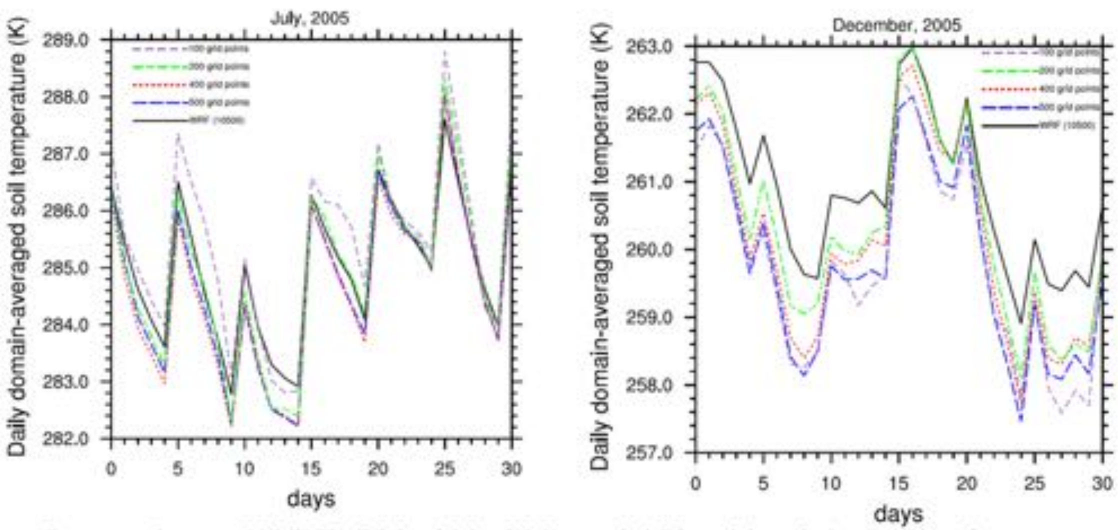
Network design and density play a role for capturing regional climatologies correctly



CCSM3.0, WRF and randomly chosen 500, 400, 200,100 WRF grid over Russia

- WRF-data as "grand truth"
- Randomly designed networks
- Calculate regional averages on 2.5°x2.5° grid, region
- Real, biased network provides the greatest error

Modified after: PaiMazumder and Mölders (2008)



Comparison of WRF, 500, 400, 200, and 100 grid points regional average soil temperature

Threefold strategy is needed

- Develop methods to use and extent existing data for new purposes
  - **Digitize printed data**
  - **Modeling friendly data storage (i.e. fill in days, hours with missing data instead of just listing the days, hours with measured data)**
  - **How to deal with “biased” networks (e.g. measurements only in fertile soils”?**
  - **How to deal with unknowns/missing parameters/quantities needed for model evaluation/development?**
  - **…**
- Develop and implement intelligent observational strategies that serve multiple disciplines
  - **to enhance existing data**
  - **to be able to answer system questions**

  ⇒We have to go beyond thinking in our own discipline
- Measure both state quantities and fluxes to close energy and water balance

References

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