Atmospheric measurements as a prerequisite for modeling the Arctic climate system

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This talk:

1. Arctic-Global climate interactions and the need for high-quality atmospheric measurements in the Arctic

2. Atmospheric key parameters and high-resolution modeling with the RCM HIRHAM4

    Horizontal Structures
    Vertical Profiles
    Surface Properties
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    Turbulent Fluxes
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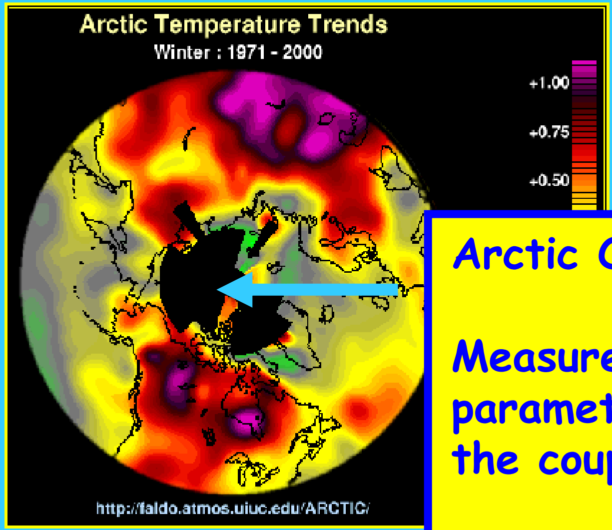
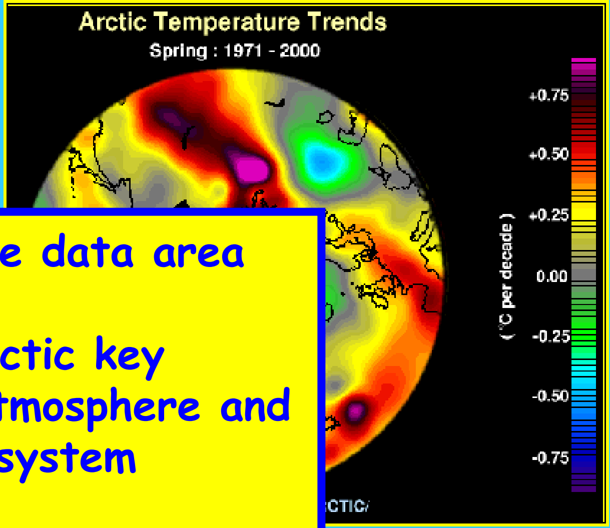
3. Regional Atmosphere-Ocean-Sea-Ice-Land System of the Arctic

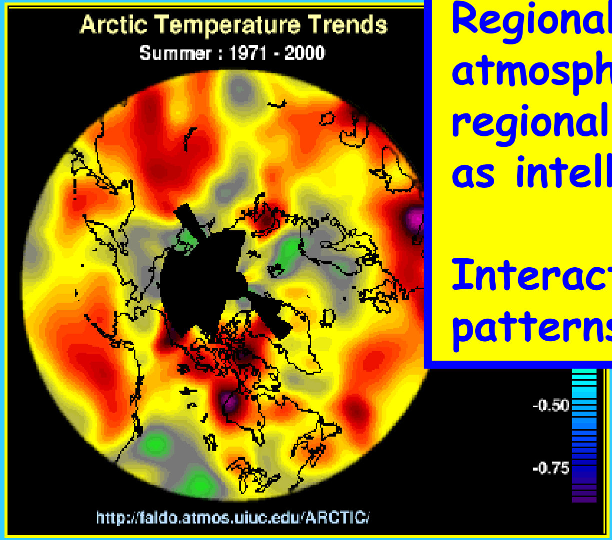
    State of the coupled climate system A-O-I-L

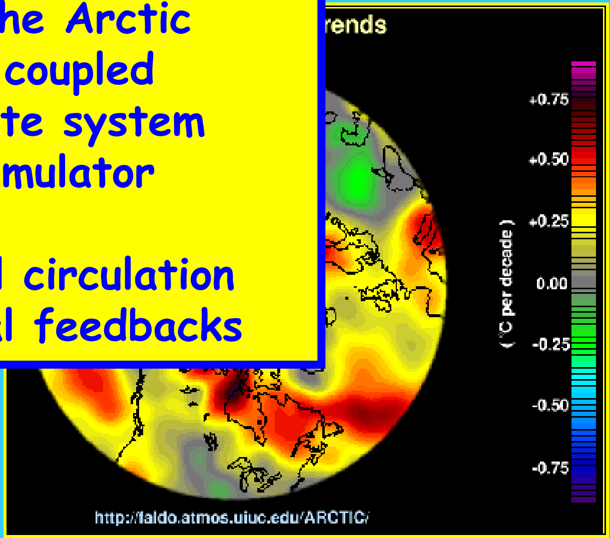
Arctic temperature trends 1971-2000

Chapman and Walsh, http://zubov.atmos.uiuc.edu/ARCTIC









Arctic Ocean- sparse data area

Measurements of Arctic key parameters in the atmosphere and the coupled climate system

Regional models of the Arctic atmosphere and the coupled regional Arctic climate system as intelligent data simulator

Interaction of global circulation patterns and regional feedbacks

Simple question of origin of warming or cooling trends,
but no simple answers due to not yet understood complex interactions

Arctic natural climate variability in global data

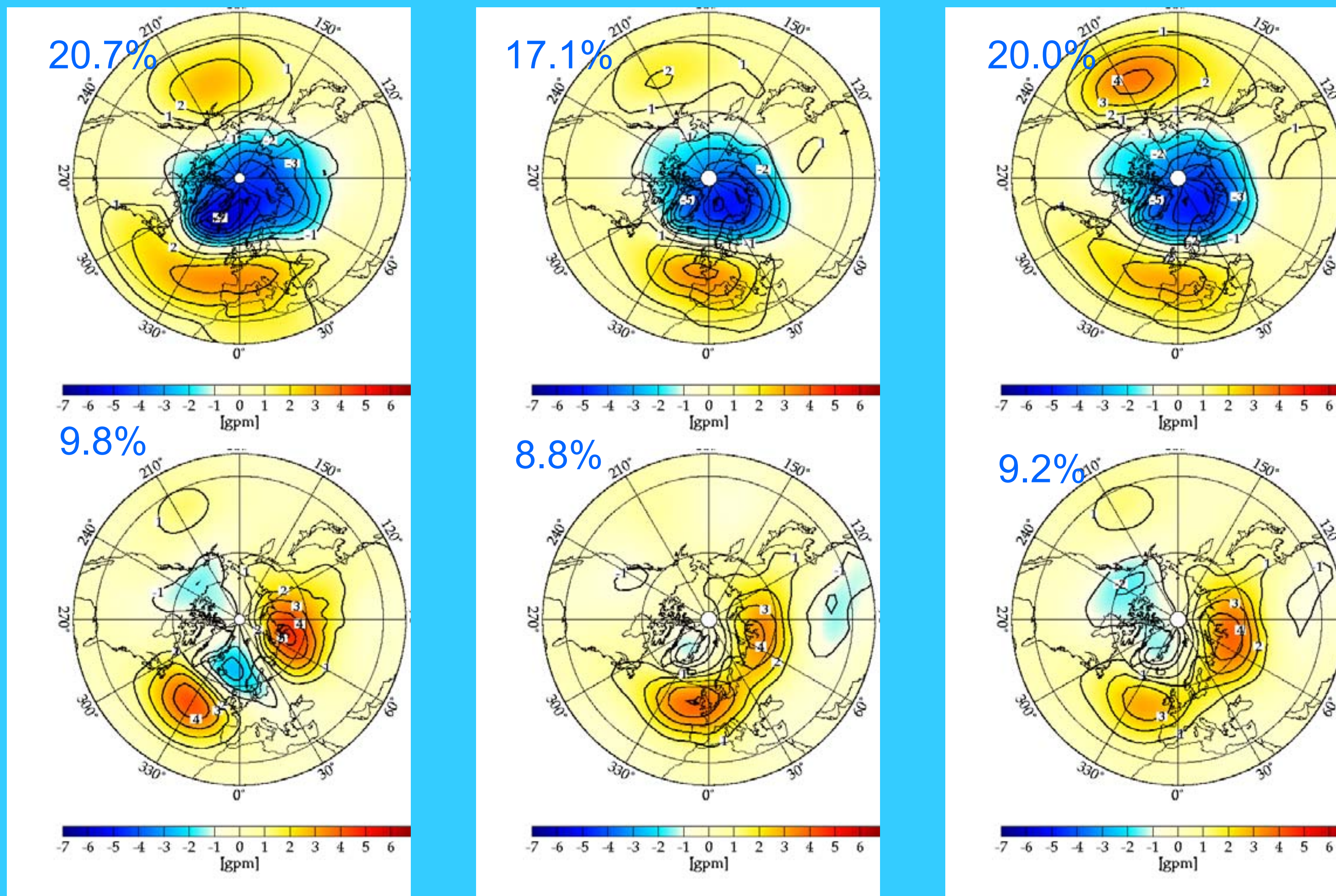
NCEP 1948-2001

ECHO-G unforced AOGCM T30, 1000yr

ECHO-G forced AOGCM T30, 1500-1990

Arctic Oscillation (EOF1)

Pattern related to Barents-Sea (EOF3)



Large scale circulation patterns in unforced and forced AOGCM, forced by solar, CO_2 and aerosol changes

Arctic climate variability in global data

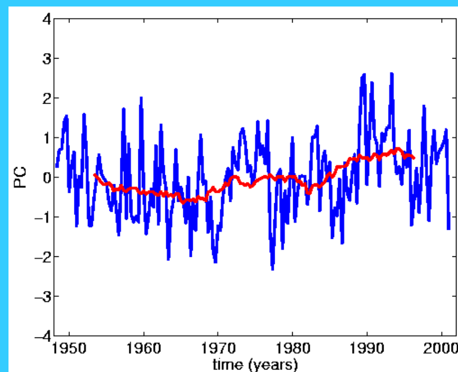
NCEP 1948-2001

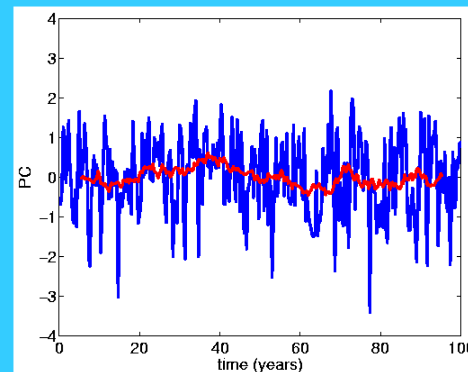
ECHO-G unforced
T30, 100yr-section

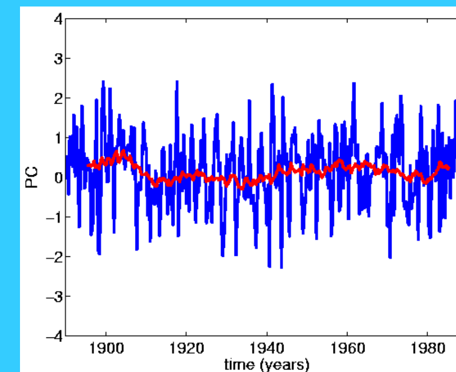
ECHO-G forced
T30, 1890-1990

Arctic
Oscillation
(PC1)

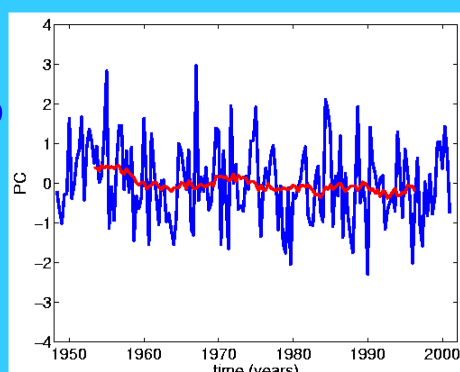
AO phases

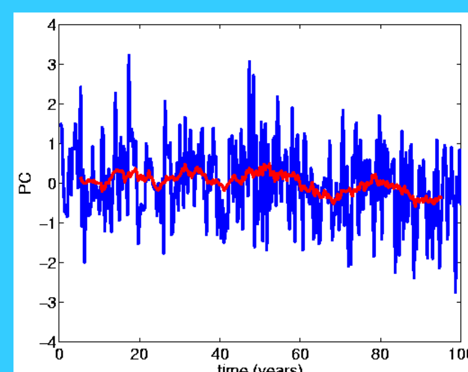


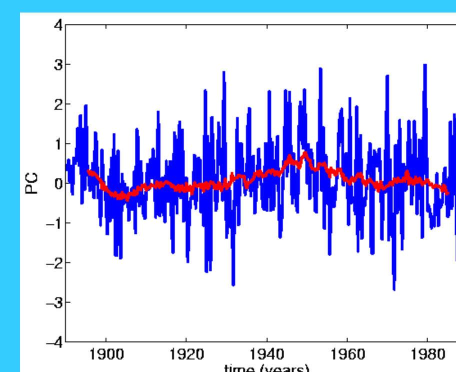




Pattern related to
Barents-Sea
(PC3)







Circulation patterns (AO, BO) and their temporal changes
Influence of external forcing, e. g. GHG, but AO changes not reproduced

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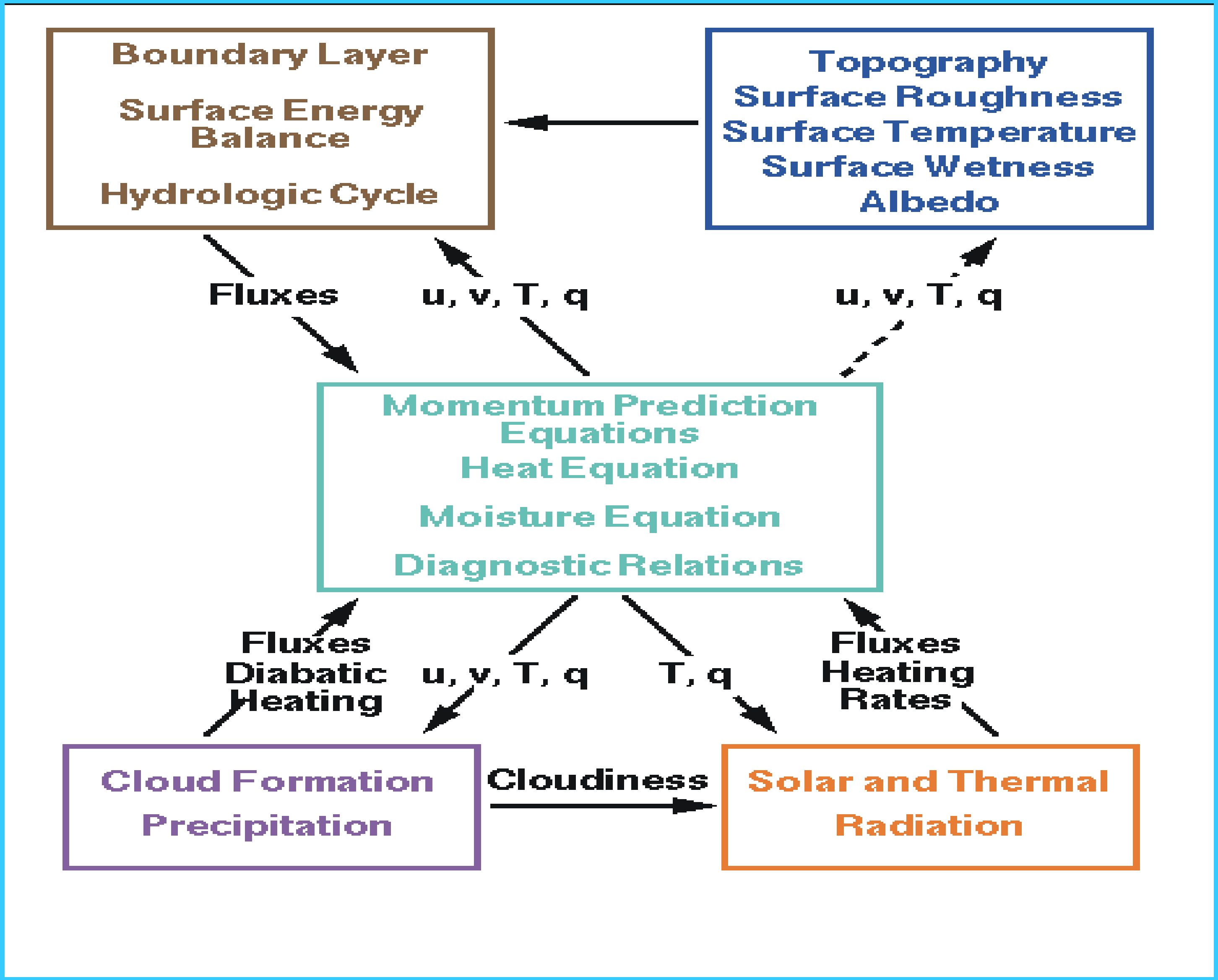
Atmospheric measurements in accordance with model simulations, Model dynamics and physical parameterization packages (PBL, Radiation)



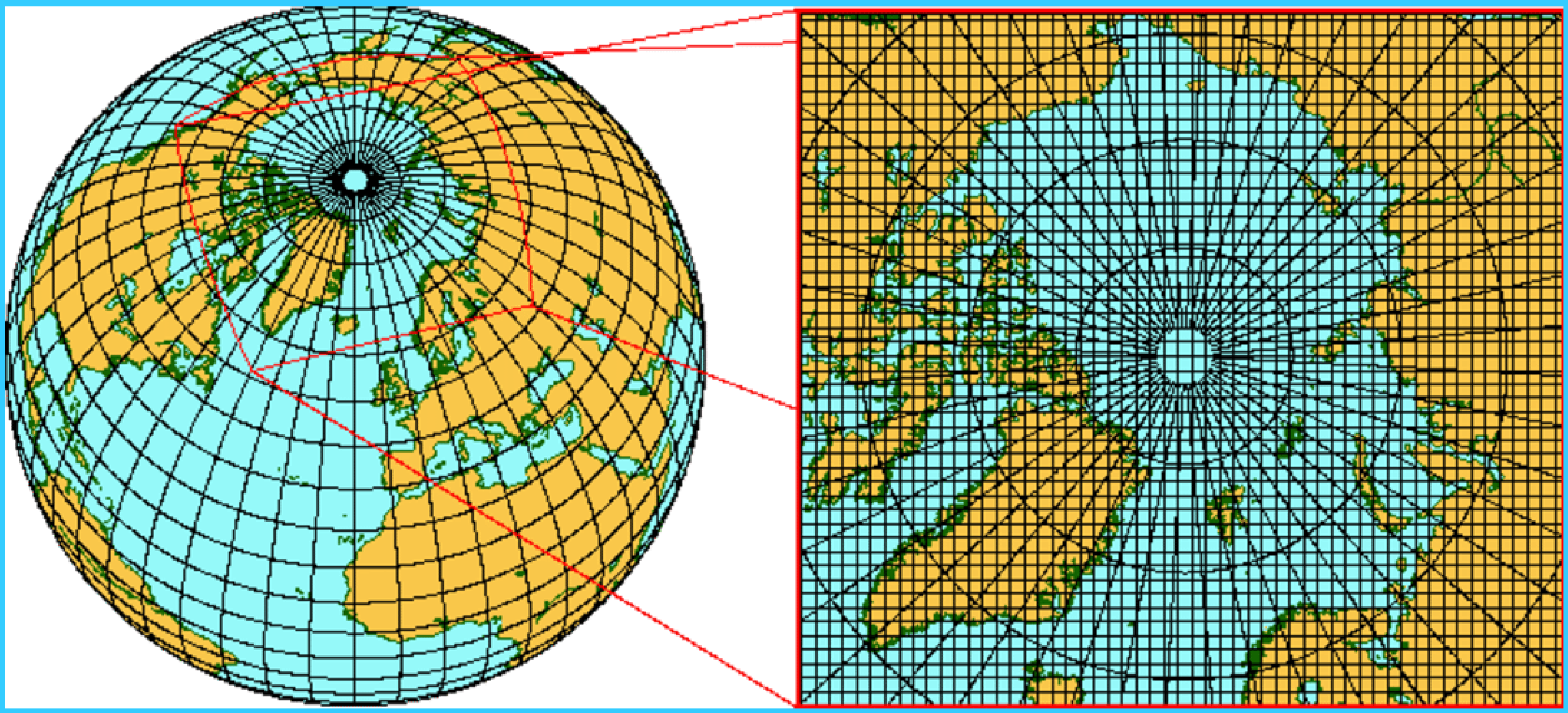
Atmospheric key parameters, bias in satellite data

Comparisons between Satellite-Derived Quantities and SHEBA Ship Measurements over the Period of 1997 to 1998. Courtesy of J. Key, NOAA Madison, 2004

Quantity	*Bias*	*RMSE*
Surface temperature	-1.43 K	2.75 K
Surface broadband albedo	-0.018 (absolute)	0.073 (absolute)
Downwelling shortwave radiation flux at the surface	9.06 W/m^2	38.16 W/m^2
Downwelling longwave radiation flux at the surface	-7.93 W/m^2	23.90 W/m^2
Upwelling shortwave radiation flux at the surface	-11.64 W/m^2	28.75 W/m^2
Upwelling longwave radiation flux at the surface	-4.81 W/m^2	9.30 W/m^2
Net shortwave radiation flux at the surface	20.50 W/m^2	23.73 W/m^2
Net longwave radiation flux at the surface	-3.28 W/m^2	20.20 W/m^2
Net all-wave radiation flux at the surface	16.48 W/m^2	29.48 W/m^2
Cloud fraction	0.13 (absolute)	0.26 (absolute)

a. Satellite-derived quantities are for the 25 x 25 km^2 area centered on the SHEBA ship.
b. Bias is defined as a difference between satellite-derived quantity and SHEBA ship measurement.

Regional climate modeling method



GCM
or ECMWF

RCM

Initial & boundary conditions
for the RCM provided by GCM

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Arctic Regional Climate Model Intercomparison Project (ARCMIP)

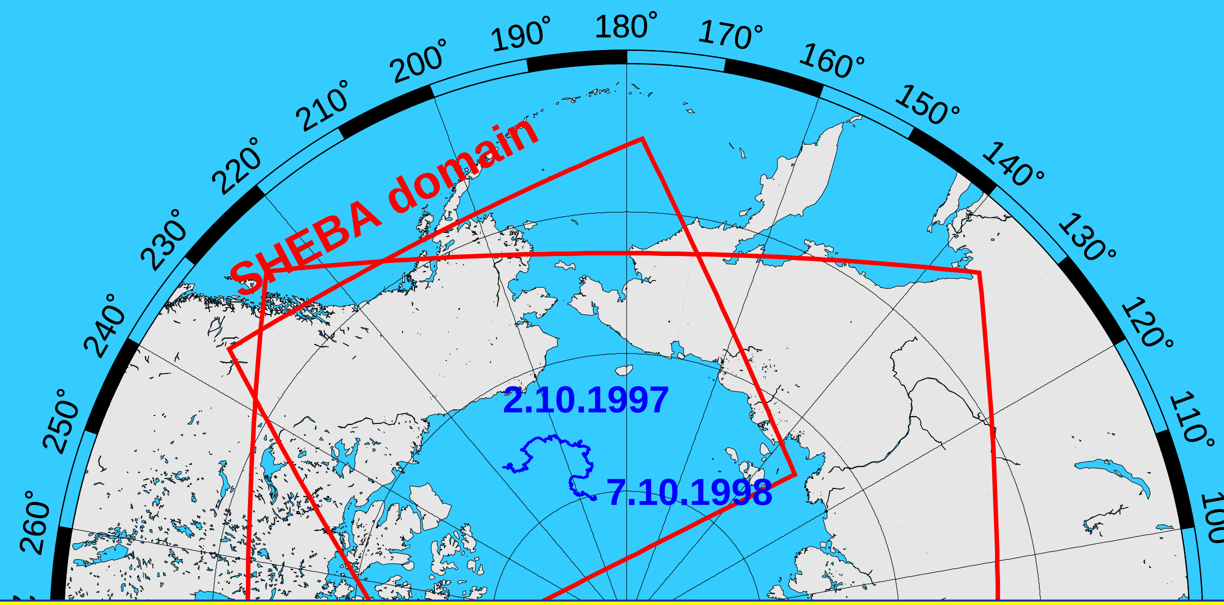
<u>Participating Models</u>

1. ARCSyM (USA)
2. COAMPS (S)
3. HIRHAM (D,DK)
4. RCA (S)
5. RegCM (N)
6. REMO (D)
7. PolarMM5 (USA)
8. CRCM (CAN)

<u>Experimental set-up</u>

- Same horizontal resolution 50 km, boundary conditions
- LBC - ECMWF operational analysis 2x2 degrees, 31 level, 6 hourly
- sea-ice fraction from 6 hourly SSM/I data,
- SST and sea-ice temperature from AVHRR surface temp.
- Different dynamics & physics
- Simulation during SHEBA year (Sept 1997-Sept 1998)

SHEBA ice camp in the Beaufort/Chukchi sea

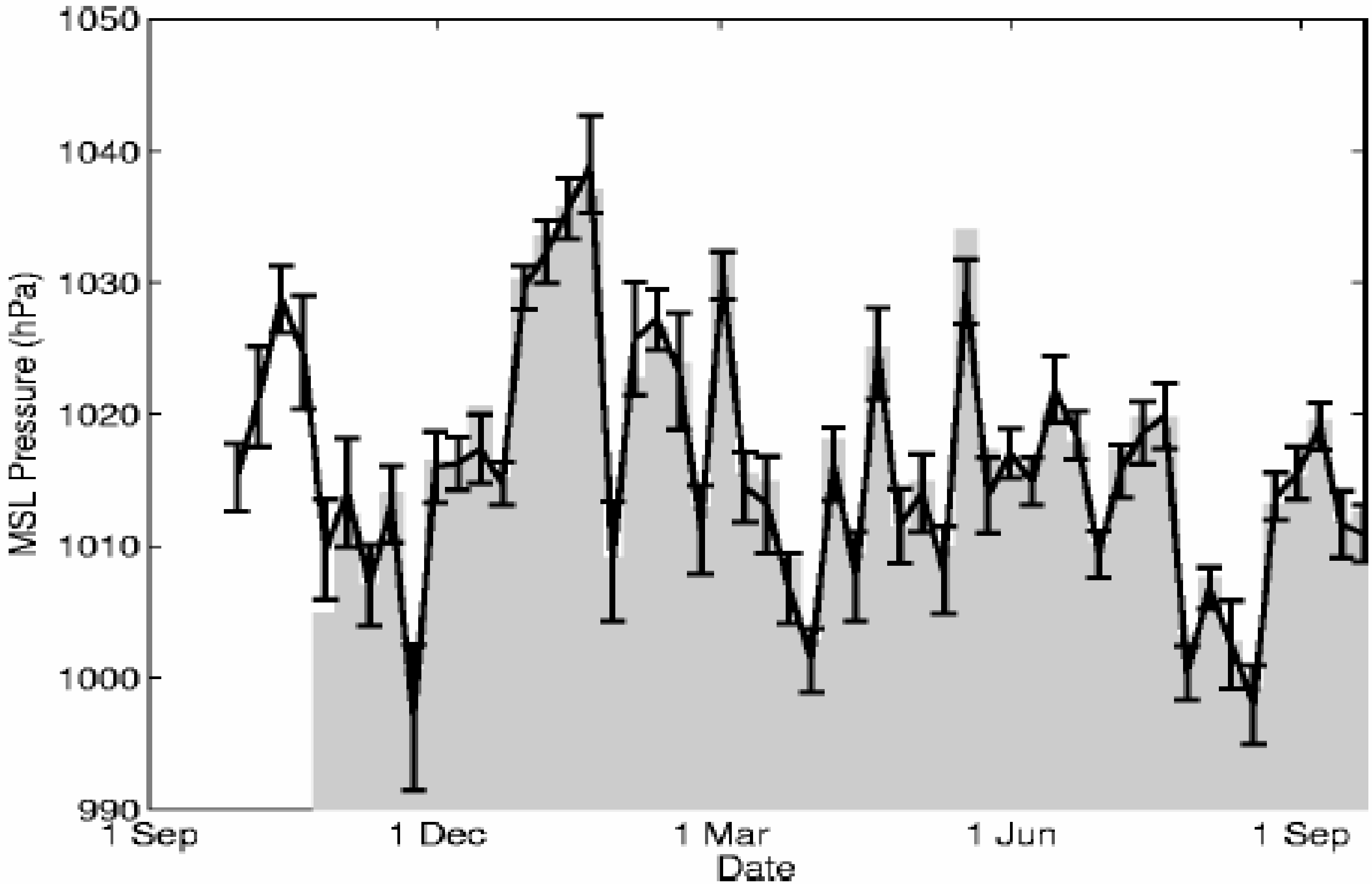


<u>Questions</u>

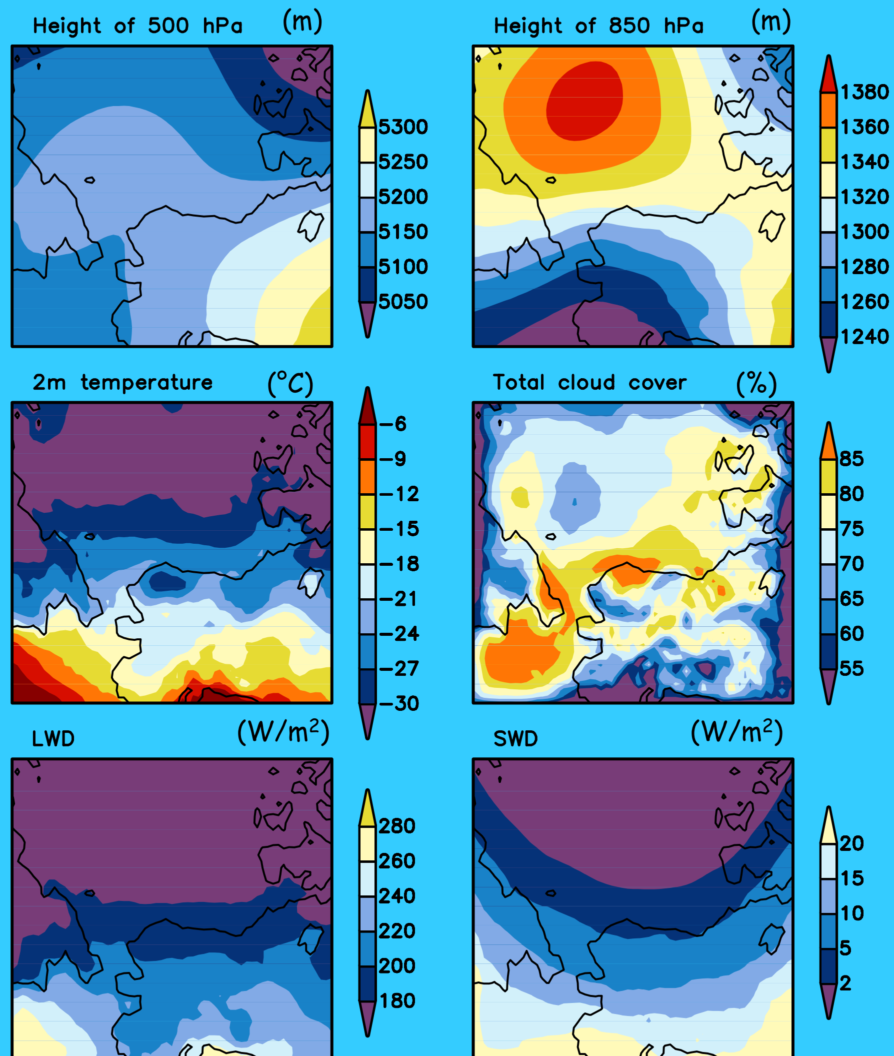
→ What is the level of uncertainty of Arctic RCMs?
→ Which processes are inadequately represented in RCMs?
→ Influence of vertical, horizontal resolution & parameterization
→ How can RCMs be best employed for scenarios (lateral forcing,multi-model approach)?
→ What can be learned about the biases experienced in AOGCM simulations of the Arctic climate?

Year long time series of weekly averaged MSLP (hPa)from the six models ARCSyM, COAMPS, HIRHAM, PMM5, RCA, REMO (black line), the inter-model standard deviations (error bars) and the SHEBA observations (grey bars),

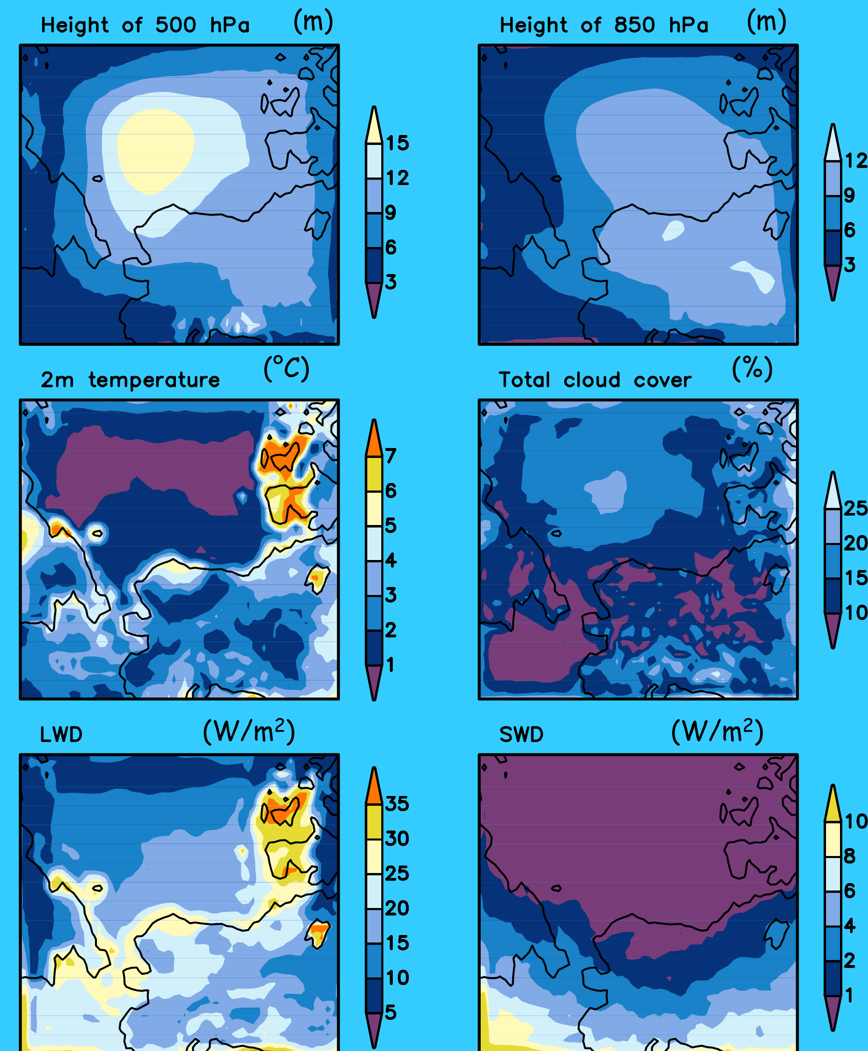
M. Tjernström and the ARCMIP group, BLM, submitted, 2004.



Winter ensemble mean



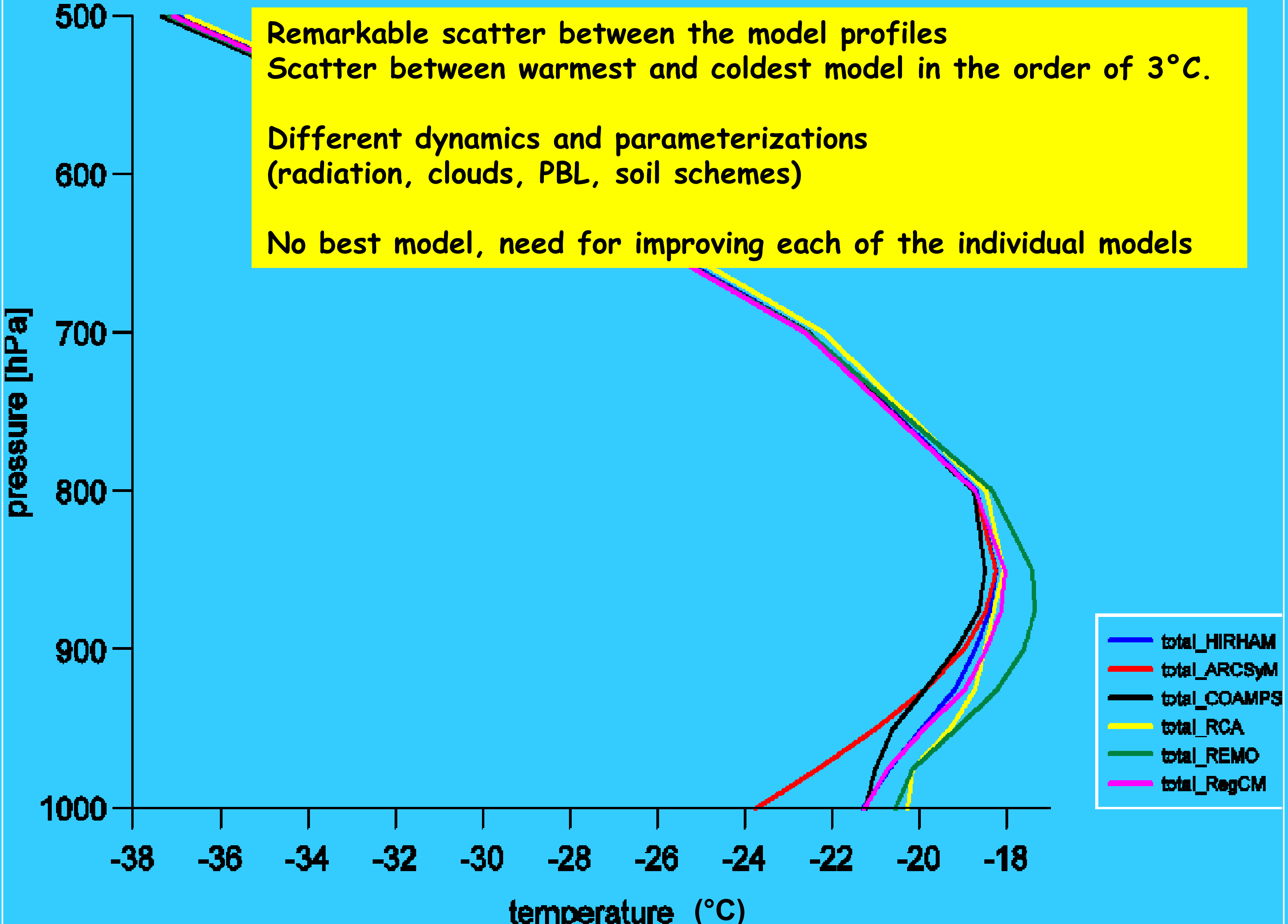
Winter ensemble stdev.



Realistic reproduction of the observed winter climate, geopotential height 850 & 500 hPa, 2 m temperature, total cloud cover, longwave and shortwave downward radiation,

Scatter between the participating models
- **2m temperature over land up to 5K**
- **surface radiation fluxes up to 55 W/m²**
- **cloud cover 5-30 %**

Temperature, winter, model



Remarkable scatter between the model profiles
Scatter between warmest and coldest model in the order of 3°C.

Different dynamics and parameterizations
(radiation, clouds, PBL, soil schemes)

No best model, need for improving each of the individual models

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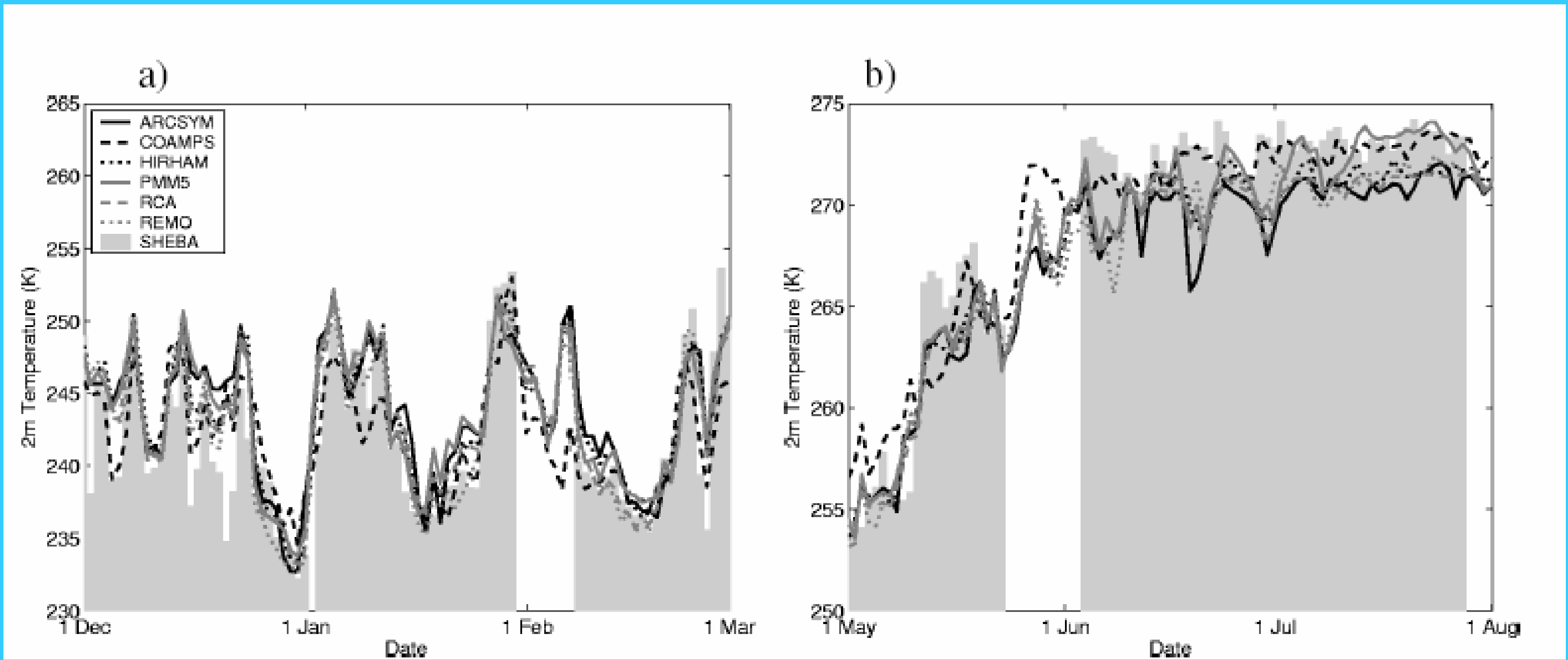
Time series of daily averaged temperature (K) at 2m for a) winter and b) late spring and early summer from the six models ARCSyM, COAMPS, HIRHAM, PMM5, RCA, REMO and the SHEBA observations (grey bars), M. Tjernström and the ARCMIP group, BLM, submitted, 2004.



Monthly averages of the SHEBA year 1997/98

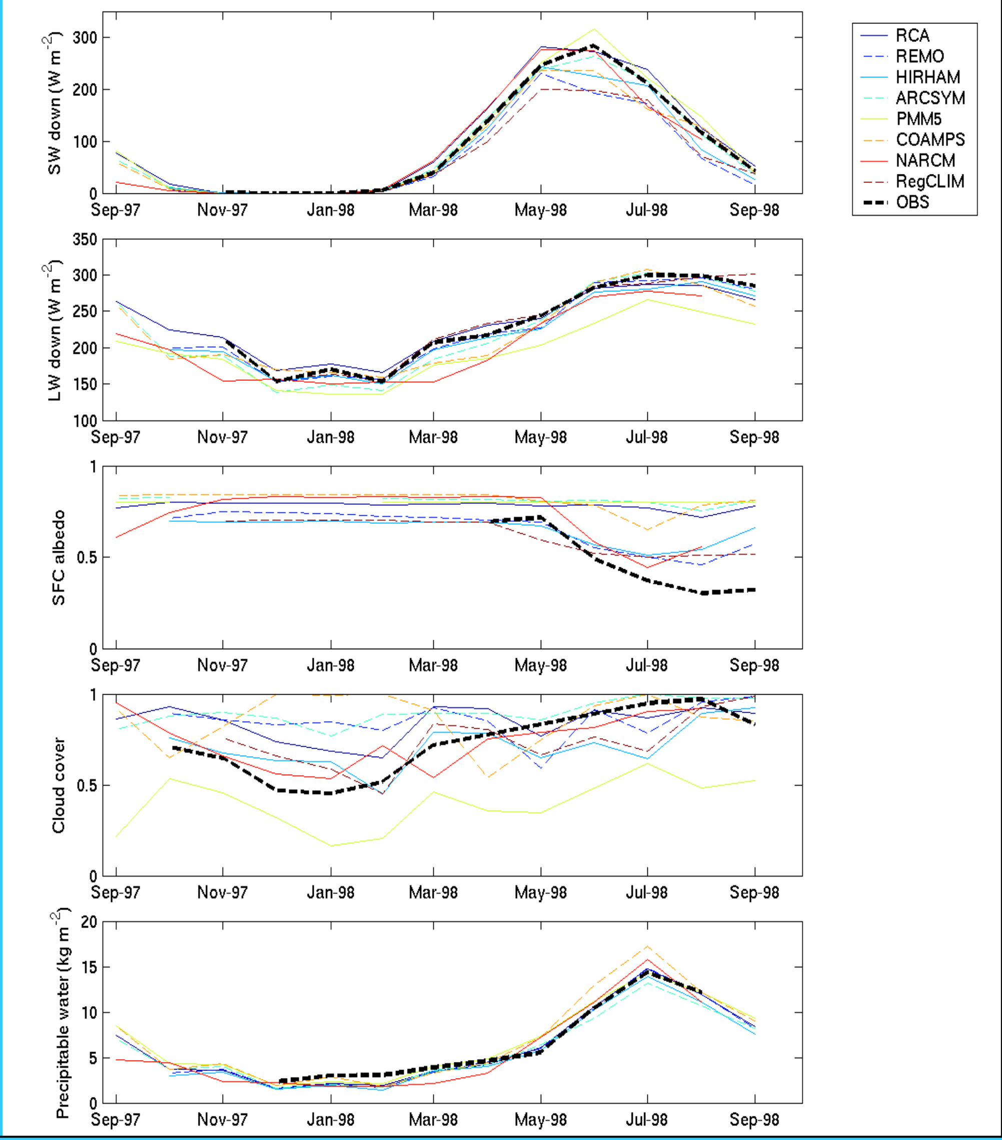
Most models show the peak solar insolation in May, but the observed maximum is in June.

Underestimated SW radiation during summer in most models, is most likely caused by a too low reflection from cloud base.

The downwelling LW radiation agrees well between models and observations.

Some models show deficits in cloud cover and/or water vapour that directly translate to deviations in the downwelling LW radiation.

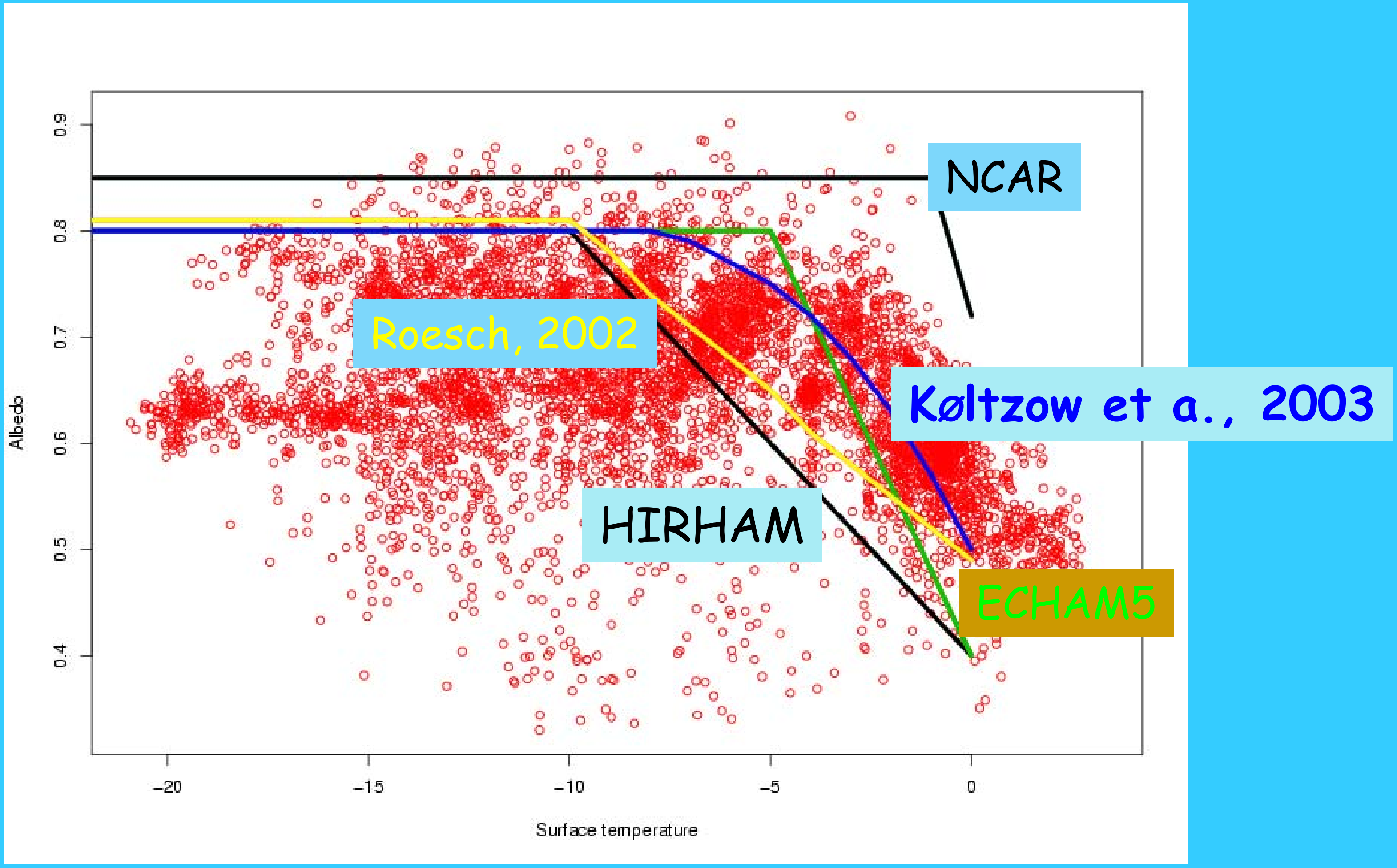
Biggest uncertainty in Arctic climate simulations are albedo and cloud cover



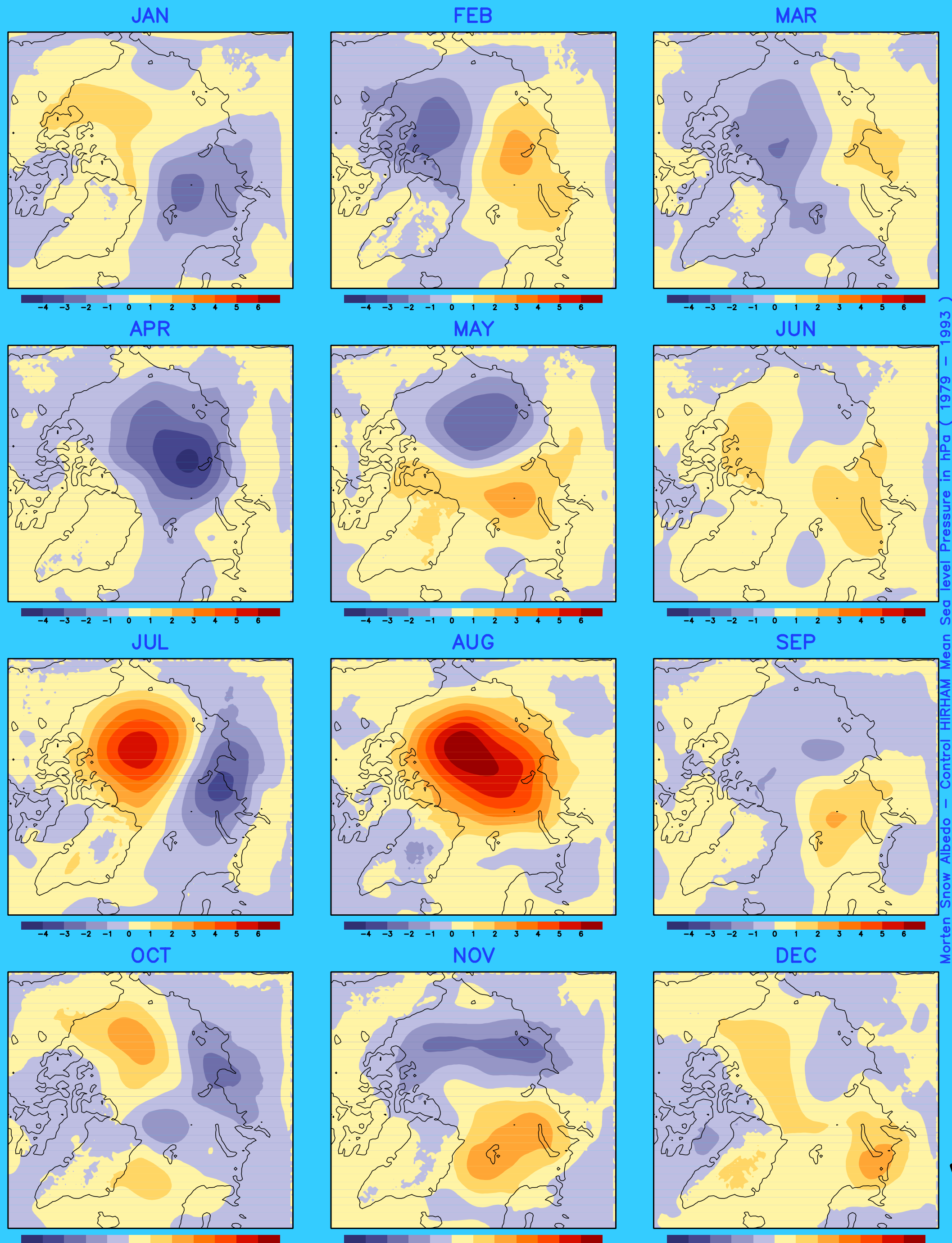
ARCMIP simulations and satellite data during the SHEBA year,
(**K. Wyser, C. Jones and the ARCMIP group 2004)**

Broadband albedo plotted against surface temperature from AVHRR (red circles) for non-forested areas. The curves are different snow albedo schemes.

Polynomial dependence(blue) from Køltzow et al., 2003



Køltzow et al. (2003), developed a new snow and sea-ice albedo parameterization on the basis of the SHEBA ice camp and satellite data



Remote influence of snow albedo changes over land on the mean sea-level pressure over the Arctic Ocean, 5 years (1979-1983)

Strong changes throughout the year

Influence of snow and sea-ice albedo changes on MSLP should be expected also in a coupled A-O-I-L RCM, where feedbacks with the sea-ice concentration can exist.

MSLP (hPa) (1979-1983)
"Køltzow 2003 minus Control run"

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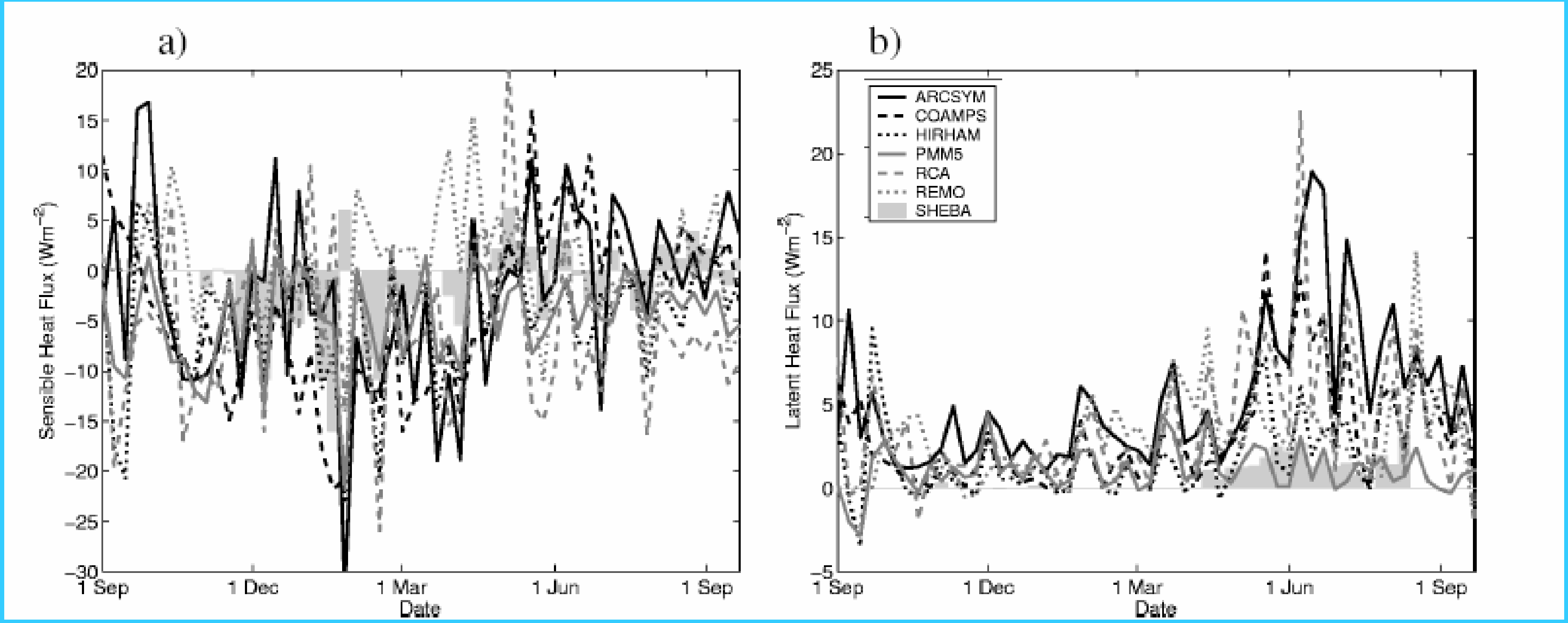
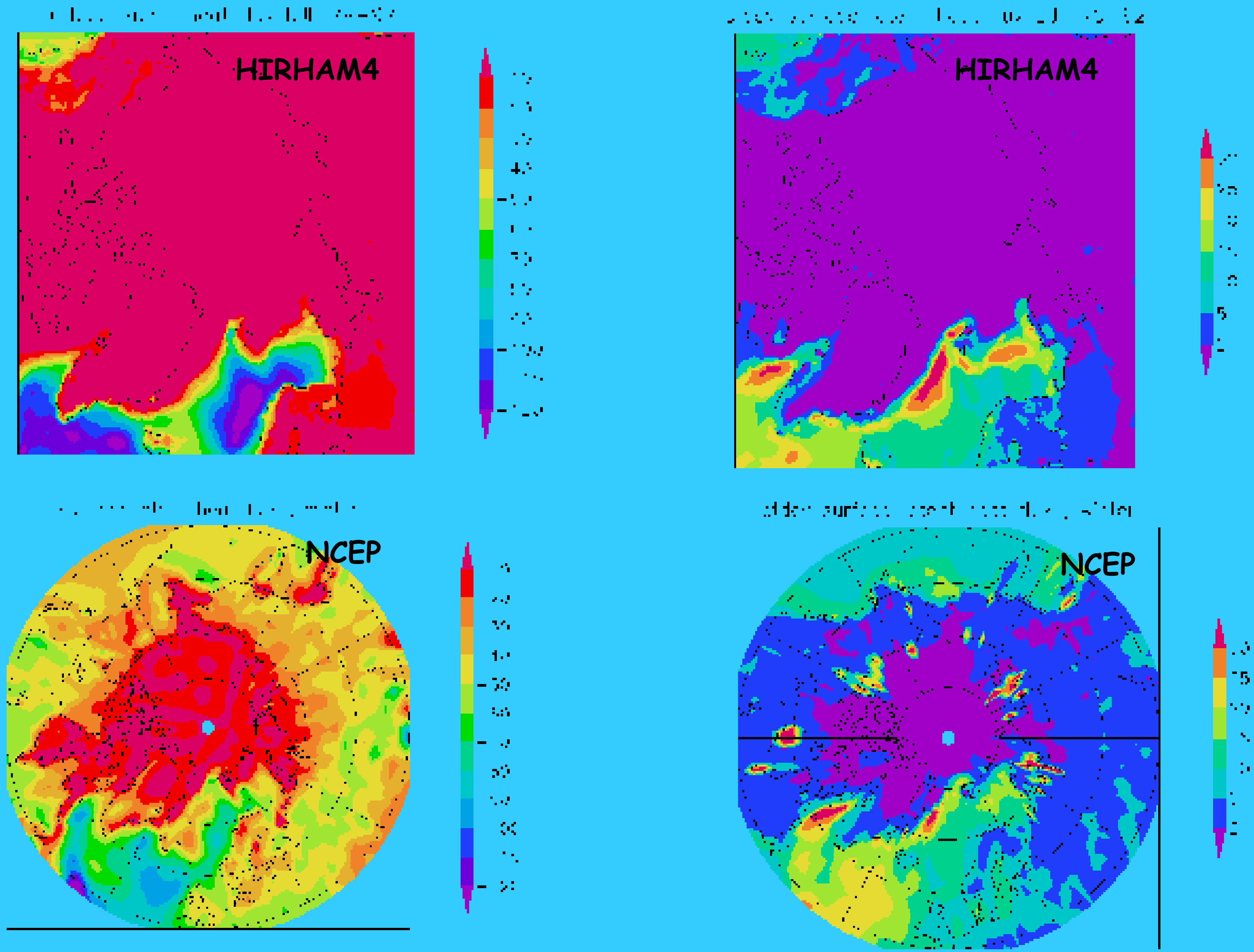
Year-long time series of weekly averaged a) sensible heat flux (W/m^2) b) latent heat flux (W/m^2) from the six models ARCSyM, COAMPS, HIRHAM, PMM5, RCA, REMO and the SHEBA observations (grey bars),

M. Tjernström and the ARCMIP group, BLM, submitted, 2004.

Big differences between model simulations and SHEBA data



Surface latent heat flux – Winter (W m^{-2})
Regional differences between NCEP and RCM



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Direct climatic effect of Arctic aerosols in HIRHAM4

(Implementation of an aerosol block without advection of aerosols,

Strong Arctic aerosol loading in Spring, Arctic Haze)

Initial data: $u(x,y,z)$ $v(x,y,z)$ $p_s(x,y)$
$T(x,y,z)$ $q(x,y,z)$ $q_w(x,y,z)$ $A(x,y)$ $\theta(x,y)$

↓

Effective aerosol distribution as function of (x,y,z)

↓

Direct aerosol forcing in the vertical column

↓

Additional diabatic heating source $Q_{add} = Q_{solar} + Q_{IR}$

↓

Dynamical changes: $\Delta u(x,y,z)$ $\Delta v(x,y,z)$ $\Delta p_s(x,y)$
$\Delta T(x,y,z)$ $\Delta q(x,y,z)$ $\Delta q_w(x,y,z)$

↓

New effective aerosol distribution
due to 8 humidity classes in the aerosol block

Aerosol – Radiation -

Circulation - Feedback

T = temperature

u, v = horizontal wind components

q = spezific humidity

$\mathbf{q_w}$ = cloud water

$\mathbf{p_s}$ = sea level pressure

A = surface albedo

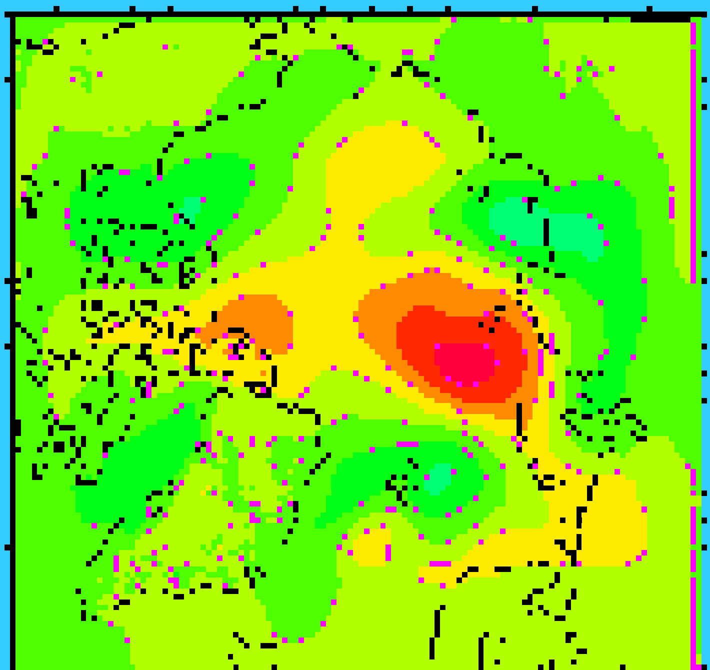
Θ = zenit angle of the Sun

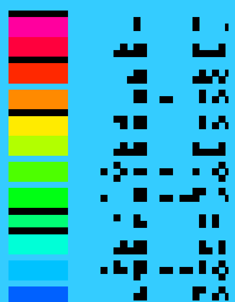
Direct radiative forcing effect of aerosols on the mean sea level pressure

(ensemble of 8 March months)

(Aerosol run minus Control run)

ECHAM4 cloud parameterization
(Rockel et al., 1991)



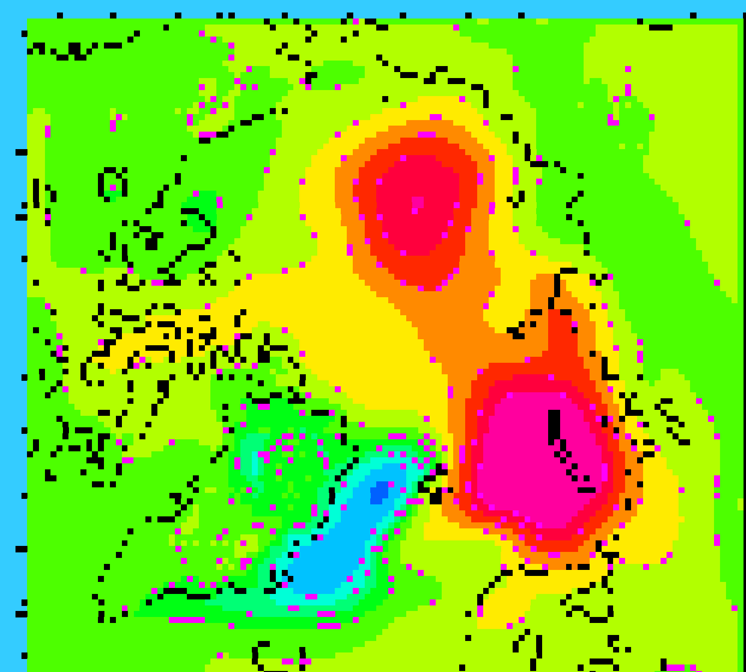


Influence of cloud parameterizations on the mean sea level pressure as indirect aerosol effect

(Cloud run minus Control run)

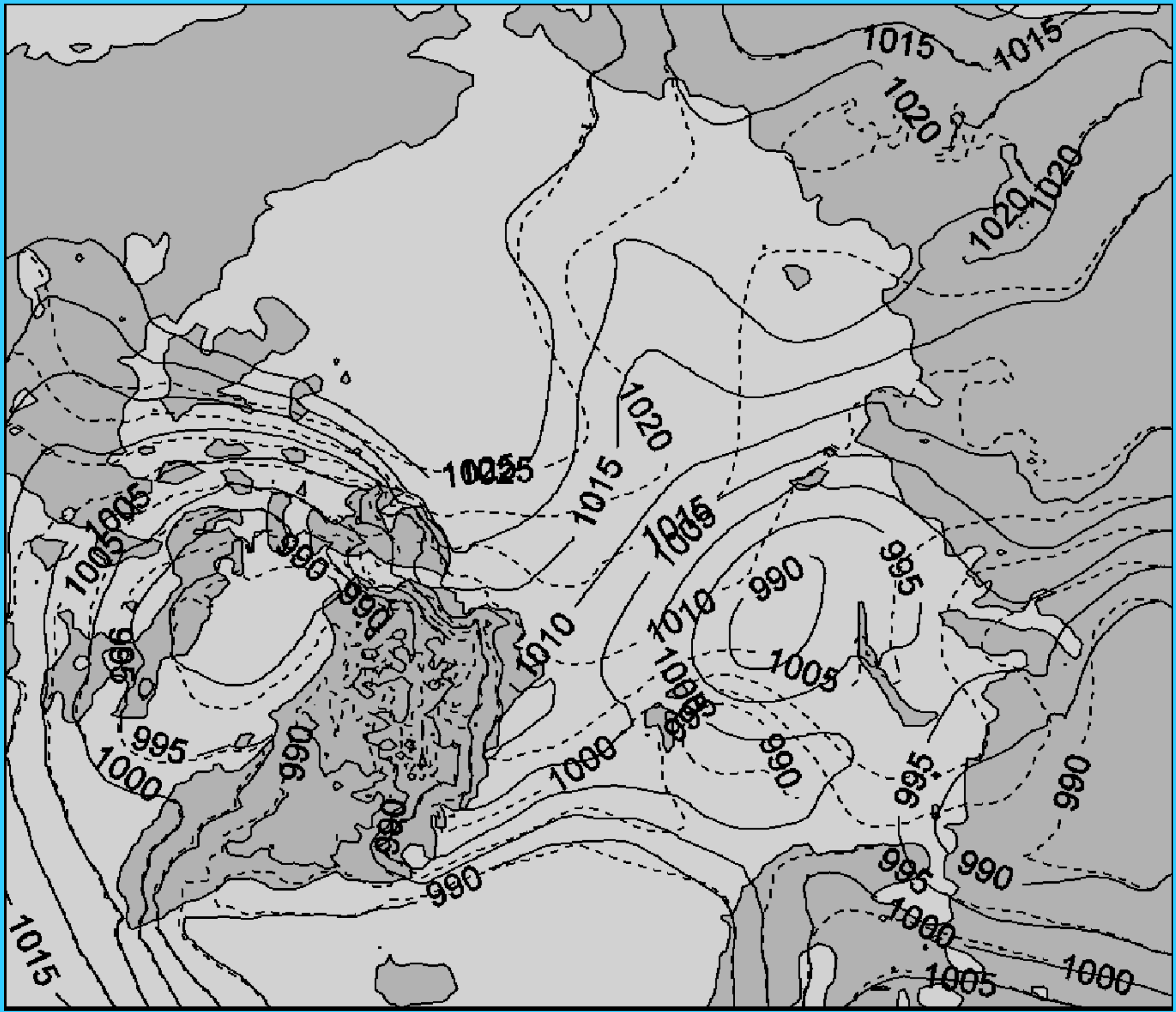
Indirect aerosol effect taken into account
Cloud droplet concentration depends on sulfate mass, (Boucher et al., 1995)

Changes in the optical properties of water clouds



Impact of indirect aerosol effects on the Barents Sea Oscillation

SLP fields (hPa) after 20 days of simulation for March 1990.
Control run (solid lines) and Aerosol run (dashed lines).
Changes in the development of cyclones over the Arctic Ocean



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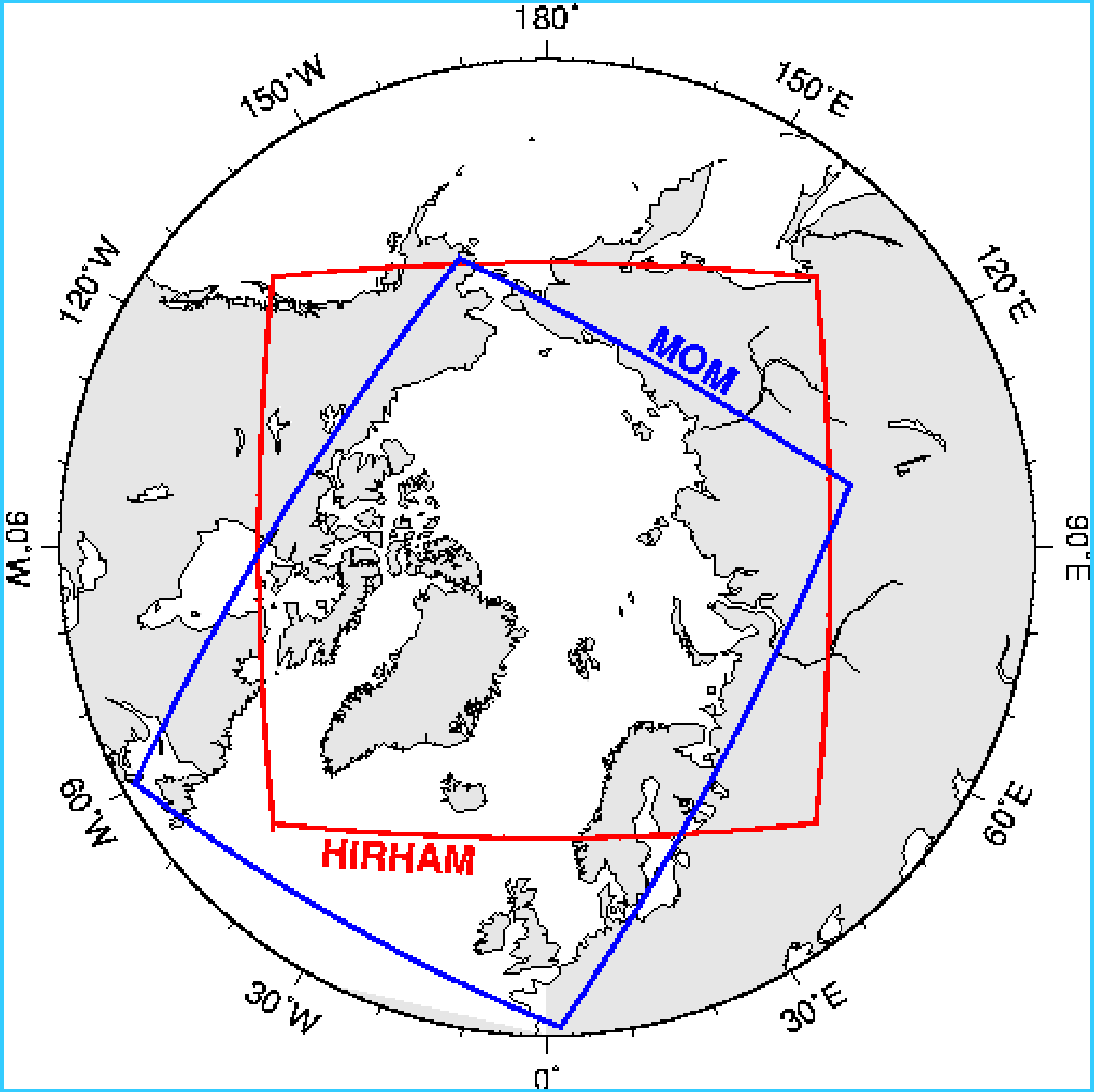
Integration domain of the coupled A-O-I model PARHAM/MOM



Atmosphere model PARHAM
- parallelized HIRHAM
- 110×100 grid points
- horizontal resolution 0.5°

Ocean model MOM (+EVP)
- AWI's regional NAOSIM
- 242×169 grid points
- horizontal resolution 0.25°

	PARHAM	MOM
Equations	hydrostatic; prognostic equations for u, v, T, q, q_w, p_s; diagnostic equations for ω, Φ.	Ocean: hydrostatic; progn. eq. for u, v, T, S; diagn. eq. for w, ρ, p. Ice: progn. eq. for u, v, A, h, h_{sn}.
Physical parame-terizations	radiation, land surface processes, sea surface sea-ice processes, vertical diffusion (PBL), gravity wave drag, cumulus convection, large-scale condensation.	Ocean: const. vertical diffusion coefficients, convection, salt restoring, no river inflow. Ice: EVP rheology, one layer with optional snow cover.
Grid	Arakawa-C; horizontal res. 0.5° (50 km); 19 unequally spaced vertical levels (hybrid σ–p).	Arakawa-B; horizontal res. 0.25° (25 km); 30 unequally spaced vertical levels.
Timing	Time step: 300 s, semi-implicit leapfrog; A–O coupling 3600 s.	Time step: 900 s (for O, I, and O–I coupling); O–A coupling 3600 s.
Boundary conditions	Lateral: ECMWF re-analyses (ERA) (updated every 6 h). Lower: out of ocean domain ERA (updated daily). Start: normal mode initialization using ERA.	Lateral: open southern boundary following *Stevens* (1991), else closed (O), open for outflow (I). Upper: out of atmos. domain ERA. Start: restart from uncoupled run driven by ERA.

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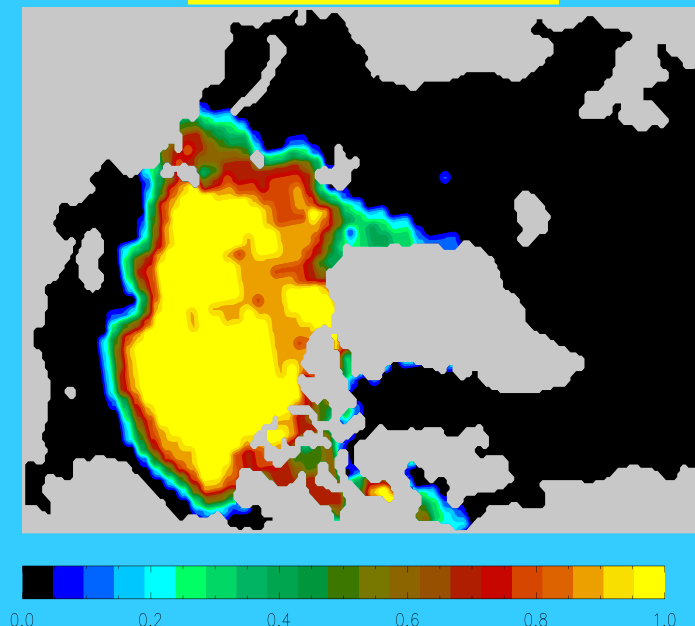
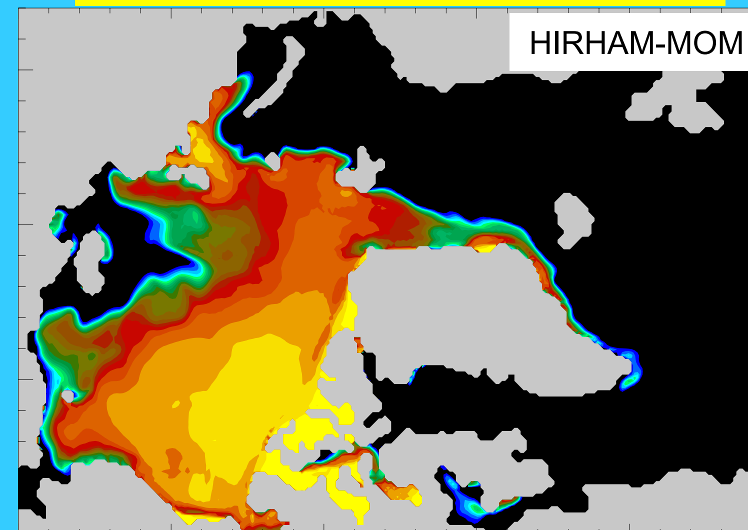
Anomalous sea ice retreat in Siberian Seas during summer 1990

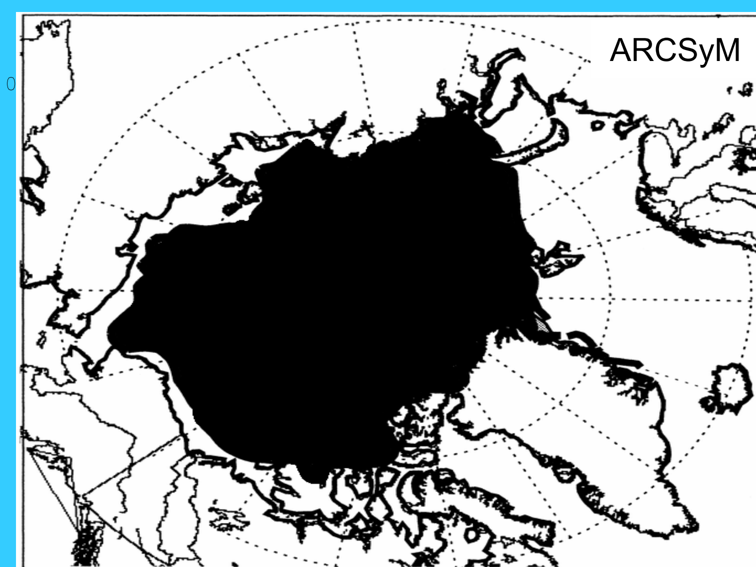
Observation

Coupled Regional Models

August 1990
Sea ice concentration







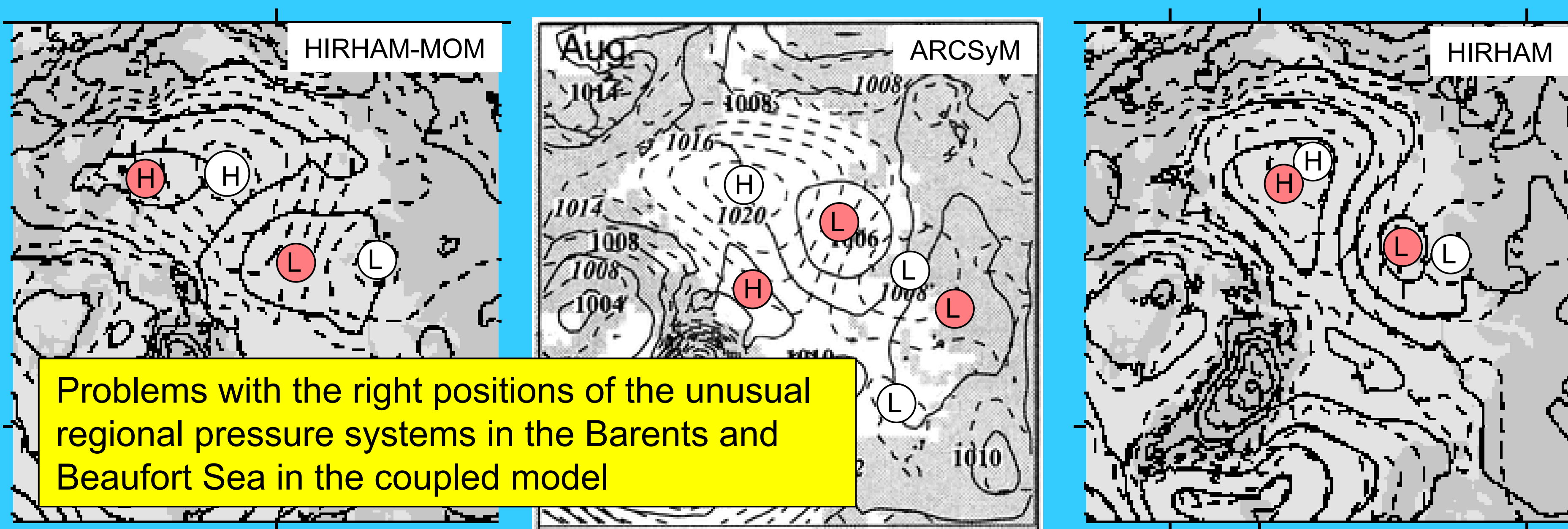
Maslanik et al., 2000
Rinke et al., 2003

Atmospheric circulation, August 1990

Mean sea level pressure (hPa)

Coupled regional models

Atmosphere-alone
with satellite sst/ice



Problems with the right positions of the unusual regional pressure systems in the Barents and Beaufort Sea in the coupled model

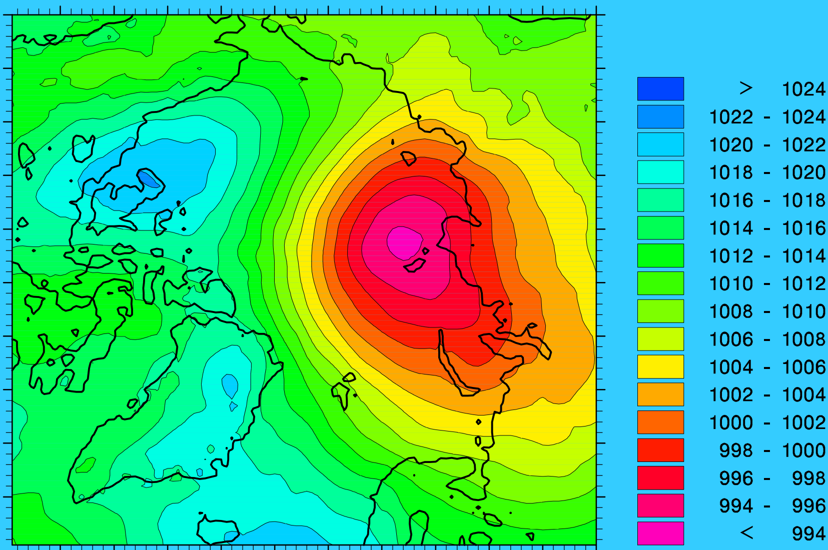
Models L

Observation L

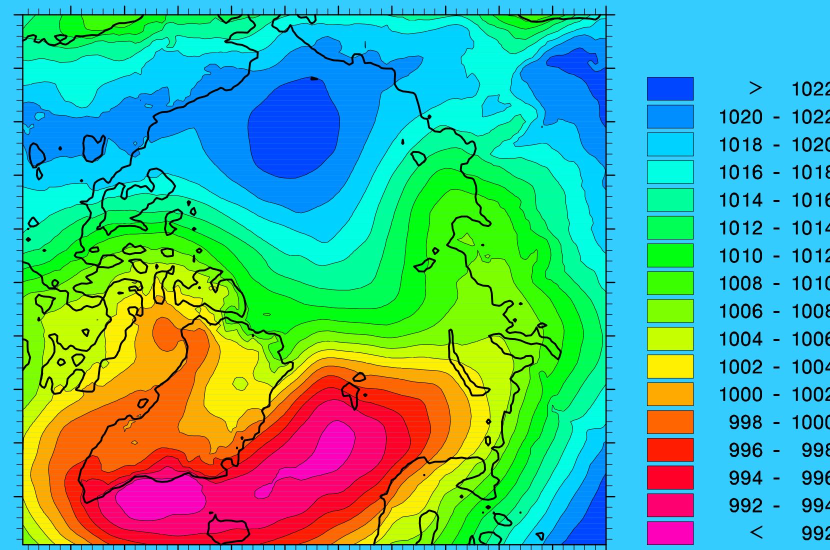
Maslanik et al., 2000
Rinke et al., 2003

Mean sea level pressure (May + Dec. 1990)

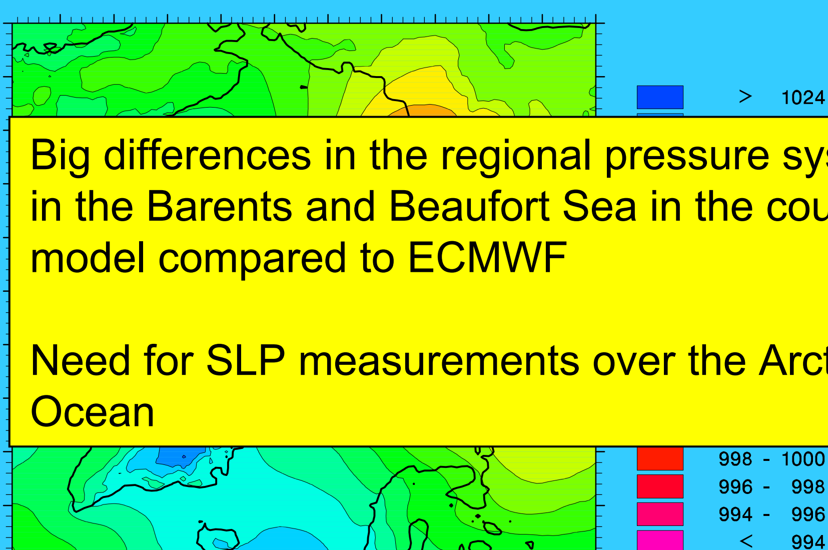
ECMWF: MSLP, 9005



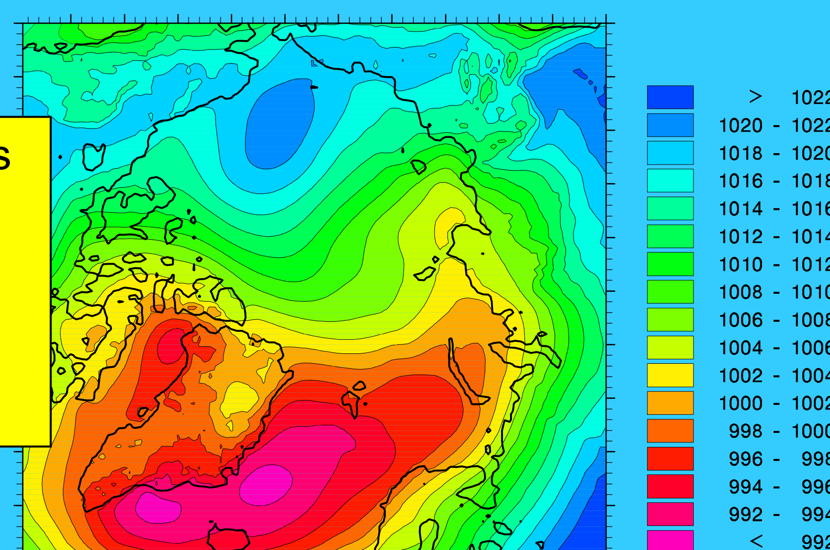
ECMWF: MSLP, 9012



PARHAM/MOM: MSLP, 9005



PARHAM/MOM: MSLP, 9012

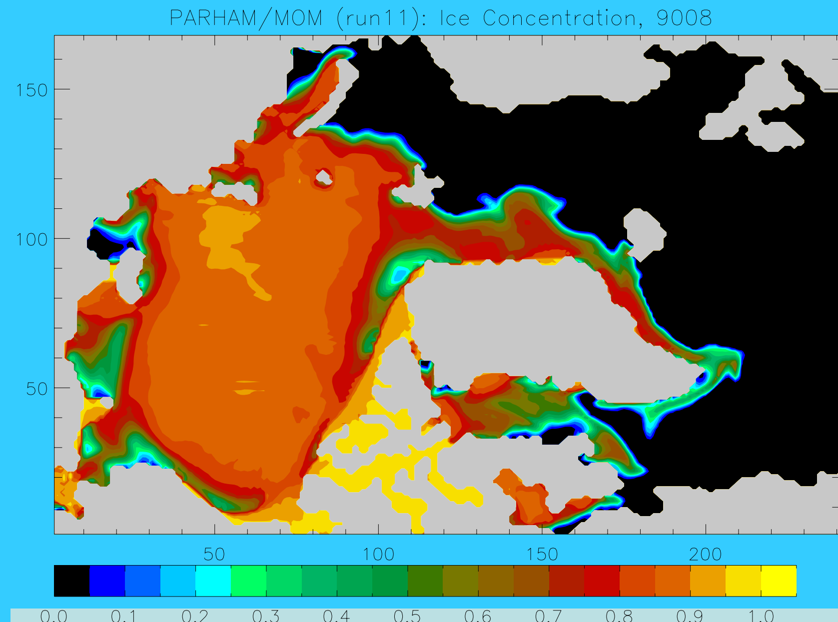


Big differences in the regional pressure systems in the Barents and Beaufort Sea in the coupled model compared to ECMWF

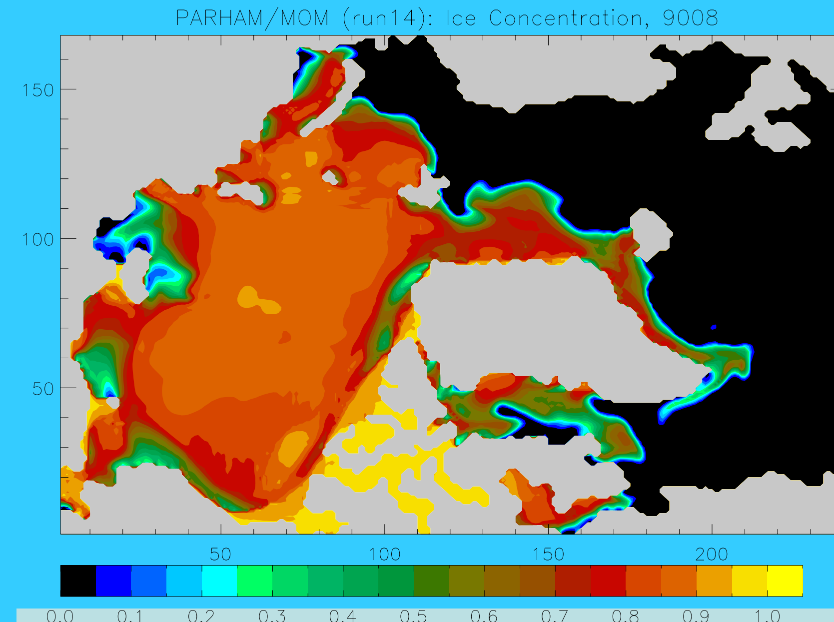
Need for SLP measurements over the Arctic Ocean

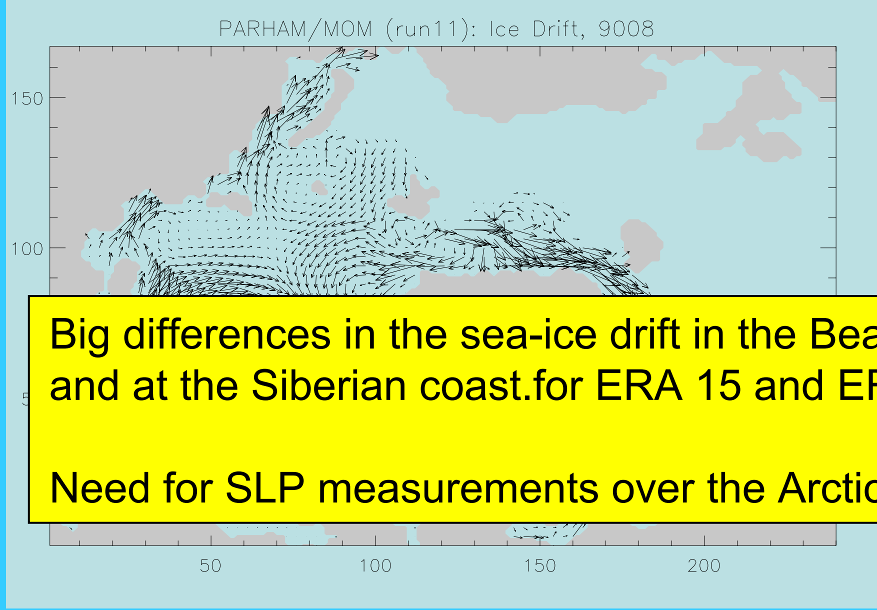
Sensitivity to lateral boundary forcing (Aug. 1990)

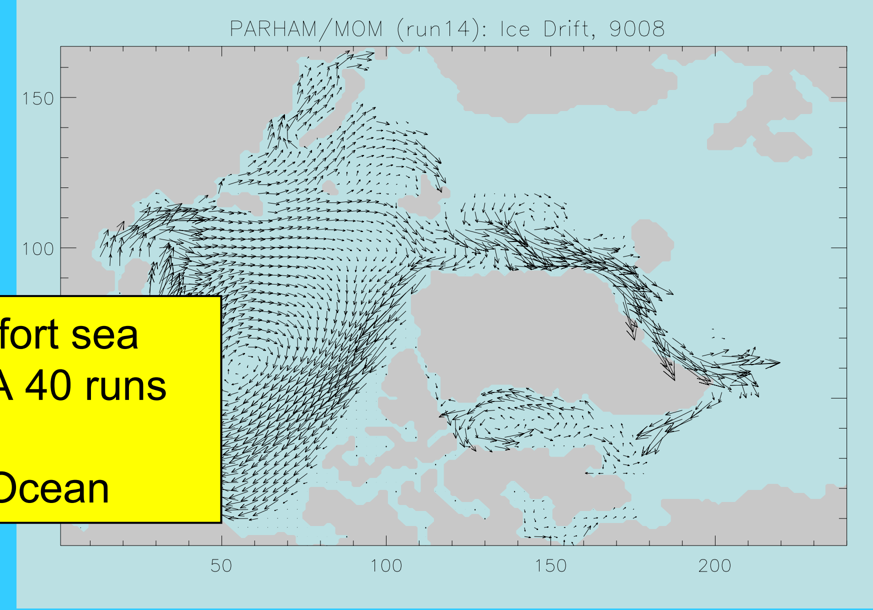
ERA-15



ERA-40







Big differences in the sea-ice drift in the Beaufort sea and at the Siberian coast.for ERA 15 and ERA 40 runs

Need for SLP measurements over the Arctic Ocean

Summary:

Many physical processes of the Arctic atmosphere are not well understood.
Many of the climate-related signals are small and masked by natural variability.

→ We need improved observations of the state variables and forcings.
→ We need means to process these and to understand them.
→ We have to set them in a coherent physical (and chemical and biological) framework with models.

Based on model intercomparison studies and analyses of existing observational high-quality data sets the following parameterizations of Arctic processes of the atmosphere have been identified as deficient in most climate models:

1 Radiative transfer
2. Surface radiative fluxes,
3. Atmospheric boundary layer,
4. Surface turbulent fluxes
5. Temperature and humidity inversions
6. Cloud micropysical properties
7. Lower tropospheric ice crystal clouds
8. Cloud life-cycle processes,
9. Convective plumes due to leads in the sea-ice
10.Sea-ice dynamic and thermodynamic processes

Need for accurate measurements of Arctic key parameters:

Surface Properties

1) Surface Temperature (2m+additional levels?)
2) Surface Albedo
3) Surface Pressure
4) Surface Wind Components (10m+additional levels?)

Cloud Properties

1) Cloud Fraction
2) Cloud Particle Phase
3) Cloud Effective Radius
4) Cloud Optical Depth

Radiative Fluxes at the Surface and the free Atmosphere

1) Downwelling Radiative Fluxes
2) Upwelling radiative Fluxes
3) Net Radiative Fluxes

Turbulent Fluxes at the Surface and the PBL

1) Sensible Heat Fluxes
2) Latent Heat Fluxes
3) Momentum Fluxes

Horizontal and Vertical structure of the Atmospheric State (days,seasons, decades)

1) Temperature, Wind components, Humidity, Clouds,
2) Constituents, Aerosols, Ozone, Other Trace Gases

State of the coupled climate system A-O-I-L (days, season, decades)

1) Land surface characteristcs (Roughness length, Vegetation,…)
2) Ice surface characteristcs (Roughness length, Thickness, Ice fraction,…)
3) Ocean state (SST, Salinity, Ocean Currents and Profiles,…)

Examples of science questions 1

- Which temporal and spatial changes occur in the Arctic atmosphere and what are their origins?
- How do regional feedbacks influence the global circulation structures?
- What kind of feedbacks does exists? How do regional changes and global changes interact?
- Which processes and atmospheric key parameters contain the biggest uncertainties?
- How accurate do we need to be in the measurements of surface properties, cloud properties, radiative fluxes at the surface and the free atmosphere, turbulent fluxes at the surface and the PBL?
- What kind of horizontal and vertical resolution of atmospheric measurements is required?
- Which atmospheric constituents should be measured and with which accuracy?
- How to produce satisfactory climate data from operational data?