Uncertainty of the recent surface temperature trends related to internal atmospheric variability

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Outline

- Some results of internal variability analysis in application to zonal SAT trends for the last 30 years: a simple model and ensemble ECHAM5 simulations

- Estimates of direct radiative forcing effect on Arctic temperature trends
Anomalous surface heating due to AMV: Zonal structure

Zonally averaged turbulent heating in the Atlantic Sector (80W-90E) associated with the AMV

![Graphs showing anomalous surface heating due to AMV with zonal structure](image-url)
ECHAM5/MLO results: annual SAT changes

Semenov et al., 2010, JC
ECHAM5/MLO results: zonal changes
CMIP5: Barents Sea sea ice area in March

Semenov et al., 2015, TCD
Ensemble ECHAM5 simulations

Resolution:  T63 L31
Boundary forcing:  monthly HadISST1 SST and SIC
Time span: 1979-2012, 34 years
Radiative forcing:  constant
Number of simulations: 45

Same boundary forcing, different initial conditions
ECHAM5/HadISST1, NCEP and CRUTEMP annual LAND (60N-90N) SAT (K) in 1979-2012
ECHAM5/HadISST1, NCEP and CRUTEMP annual LAND (60N-90N) SAT (K) in 1979-2012

The graph shows the temperature changes from 1979 to 2012, with a marked divergence beginning in 1996. The difference is approximately 0.7 K.
Why a model forced by observed SST/SIC strongly underestimates observed annual SAT trends over land?

Why is the model good before 1996 and bad afterwards?

- NAO experienced the strongest trend from 1979 to 1996
- The model ensemble mean shows three times weaker trend
- In spite of that SAT changes are very well reproduced
ECHAM5/HadISST1, NCEP and CRUTEMP
ZONAL annual SAT trends over LAND (1979-2012), C/10yrs

Where is Arctic Amplification?
What can be a reason for the inconsistency between model results and observations?

- Model formulations are wrong and incapable to reproduce the correct response to the prescribed forcing
- Model is realistic but forcing is not correct
- Model is realistic, forcing is correct but the difference is not improbable due to internal variability

  Observed trend is just one realization of the “real stochastic system” and likely belong to high end of its distribution
Uncertainty of the observed trends

Santer et al. 2000, 2008 – inconsistency between simulated and observed temperature trends in troposphere

Thompson et al. 2015 – trend uncertainty is estimated as a function of natural variability std and ar1

Trend magnitude to exceed 95% margin of error relative to the standard deviation of the internal variability (Thompson et al. 2015)

Derived by substituting in the standard relation for the residual error effective number of independent points as $N_{eff} = N (1-r_1)/(1+r_1)$

Uncertainty in future climate trends due to internal variability can be robustly estimated from the statistics of the observed climate
Stochastic AR model of temperature variability with external forcing

\[
\frac{d\theta}{dt} = -\lambda_\theta \theta + \gamma t + \Delta F(t) + f(t):\]

- Relaxation term
- Linear forcing
- SST, SIC
- Stochastic term

\[
\langle f(t)f(t+\tau) \rangle = 2D_f \delta(\tau)
\]

\[
R_\theta(\tau) = \sigma^2_\theta \exp(-\lambda_\theta |\tau|)
\]

Correlation function of the solution

\[
\tau_\theta = 1 / \lambda_\theta
\]

Relaxation time

\[
\sigma_{\theta, lin} \approx \tilde{\sigma}_\theta \left( \frac{12}{T} \right)^{1/2}
\]

STD of linear trends is a linear function of averaged SAT anomalies’ STD

\[
\sigma_{\theta, lin} \approx 0.59 \tilde{\sigma}_\theta
\]
Application to ensemble ECHAM5 simulations (annual data)

Intra-ensemble zonal trends’ STD, K

Zonal trends' STD as a function of SAT STD

Semenov, Demchenko, in preparation
ECHAM5/HadISST1, NCEP and CRUTEMP
ZONAL annual SAT STD over LAND (1979-2012), K
ECHAM5/HadISST1, NCEP and CRUTEMP
ZONAL annual SAT trends over LAND (1979-2012), C/10yrs
NCEP - ECHAM5 ens.mean annual SAT trends diff., K/34yrs
Role of sea ice in formation of wintertime Arctic temperature anomalies: ETCW phenomenon

Arctic winter sea ice and temperature

Arctic winter temperature (observed an simulated)

A role of ice and SST in simulated temperature changes

NAO response

ECHAM5 ens. mean annual Arctic SAT with and without rad. forcing
Contribution of direct radiative forcing to Arctic annual SAT, K
ECHAM5 annual Arctic SAT trend differences due to direct rad. forcing, K/34yrs
Conclusions

- ECHAM5 GCM when forced with prescribed SST/SIC strongly underestimates the observed Arctic SAT trends from the second half of the 1990s
- ECHAM5 does reproduce the observed interannual variability of zonal SAT
- Langevin model of SAT fluctuations explains the dependence of trend variability on SAT variability and fits to model results
- Based on this framework, the difference between the observed zonal SAT trends north to 65N and model spread cannot be produced by internal variability
- This points to the SIC forcing as a reason for the mismatch
- Direct radiative forcing contributed about 0.3K to the Arctic annual SAT trends in 1979-2012
Thank you!
Role of sea ice in formation of wintertime Arctic temperature anomalies

Fig. 2. Arctic cold season (November–April) SAT anomalies (°C) simulated in the HadISST ensemble mean with (blue) and without (black) data sampling according to CRUTEM3 data.