# Downscaling applications in coastal research and paleoclimatology

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# Content

- downscaling for wave hindcasts (1948 - present)
- downscaling for Mid-Holocene precipitation
- comments on Perfect Prog and Model Output Statistics

# Local wave hindcast for Helgoland area (German Bight)

## Problem

- high-resolution wave statistics for the near-shore zones are needed for coastal protection and offshore engineering

- measurements are sparse (e.g. one location, 2km from Helgoland coast)

- existing hindcasts are too coarse and don't include shallow water effects

## Approach

- simulate wave statistics with very high resolution model for several years

- validate

- use model as surrogate reality and fit statistical downscaling model, apply for several decades

(courtesy Lidia Gaslikova, Ralf Weisse)

# Wave simulations

## Low resolution wave climate from HIPOCAS

(HIndcast of dynamic Processes of the Ocean and Coastal AreaS of europe)

- dynamical spectral wave model (WAM), 5 km x 5 km, 3h output, covers North Sea

- forced with REMO winds 1948 - present

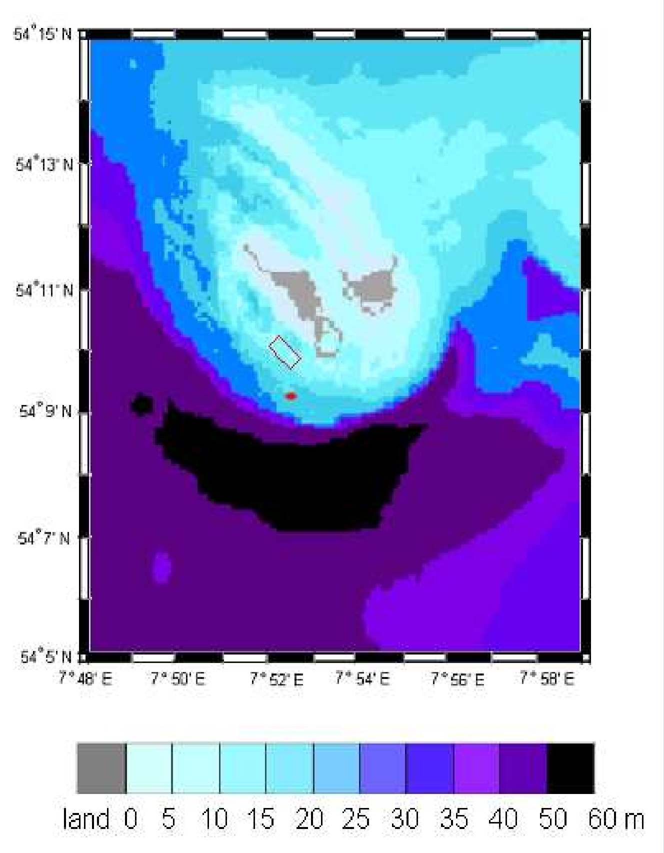
## High resolution wave climate from K-model

- spectral, shallow water, bottom dissipation, wave breaking, non-linear dissipation, refraction caused by currents and changing depth

- input: HIPOCAS wave spectra at boundaries, 10m wind from REMO (1 hour), currents, water level variations

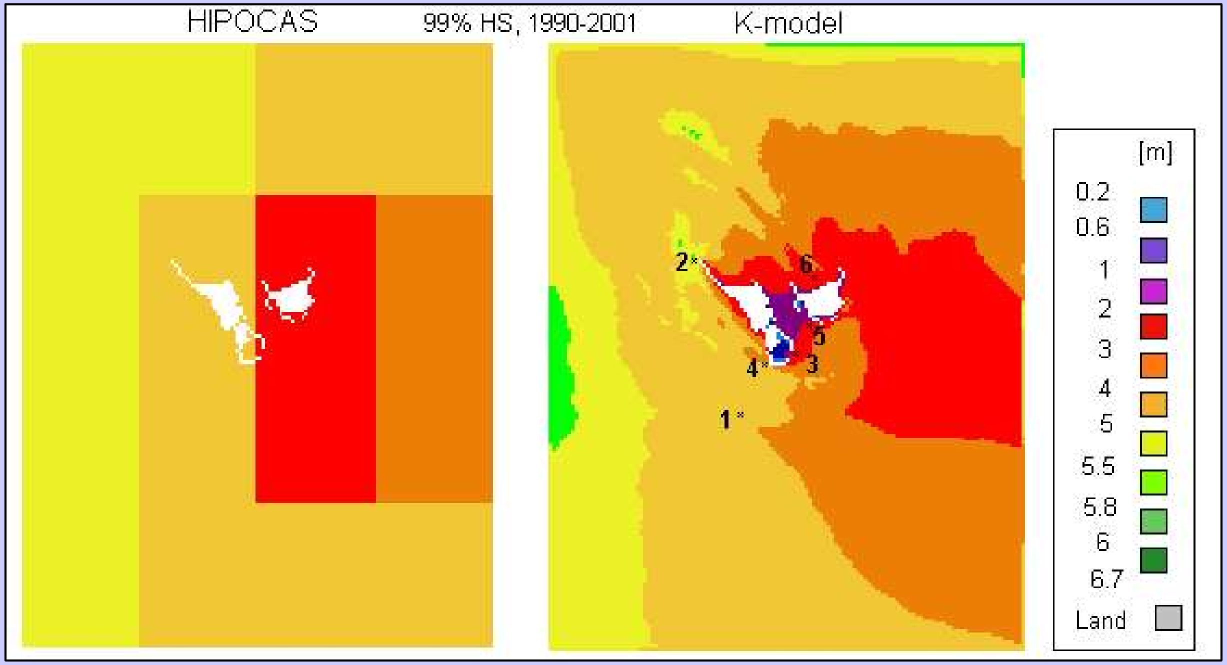
- output: 100 m, 1 h, significant wave heights peak period, peak direction, **validation OK**

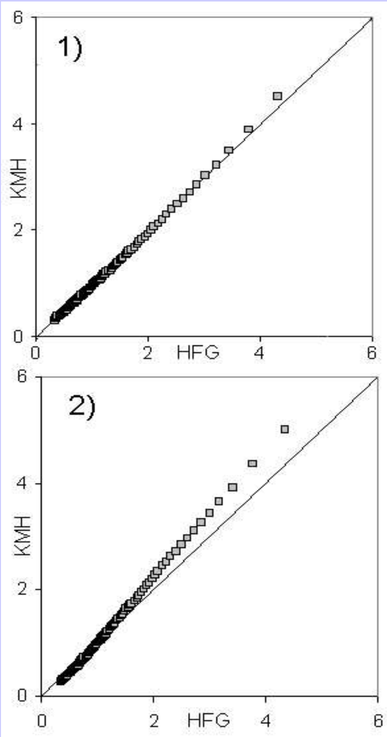
- 1990-2001, 15 000 CPUh on NEC SX6

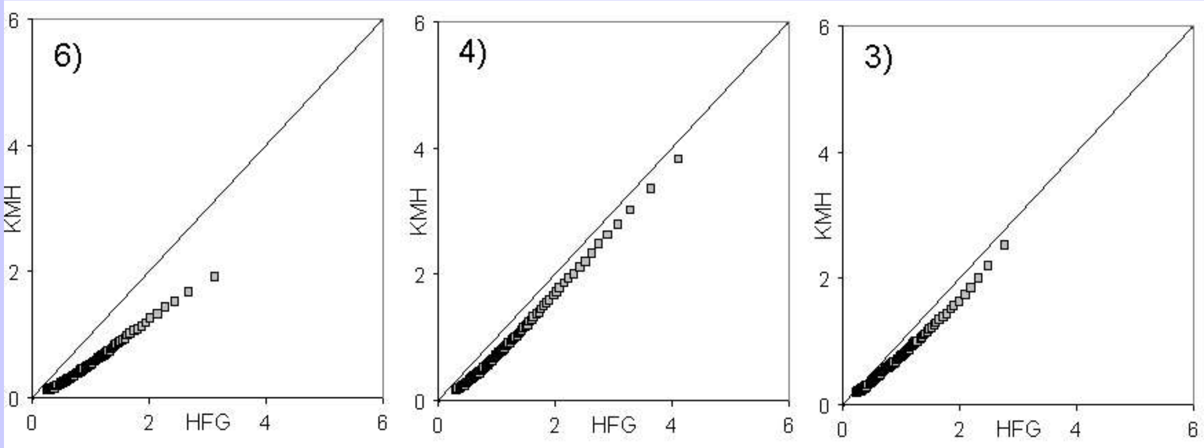


# Added value from the K-model simulation

## 99 percentile of significant wave height




**5%-99% significant wave heights HIPOCAS (x-axis), K-model (y-axis) 1990-2001, 3-hourly**

(courtesy Lidia Gaslikova, Ralf Weisse)

# Statistical downscaling

## Predictand

high-resolution significant wave height field from HIPOCAS,  3 h

## Methods

- linear regression separately for each K-Model grid point and for 8 wind segments

- PC-filtered CCA, 2 left, 2 right PCs, which explain 99.1 % and 98.3% of total variance

- analogs based on PC1 from HIPOCAS

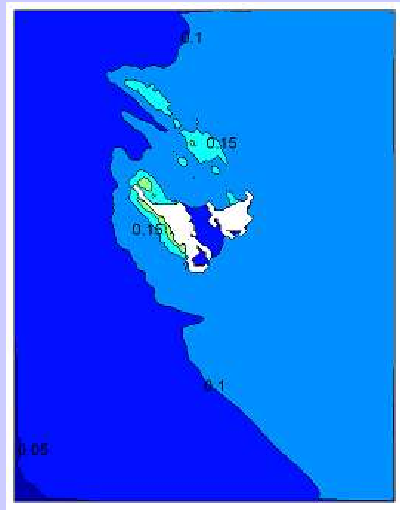
## Fitting/Validation

fitting period 1990-1994, validation period 1995-2001

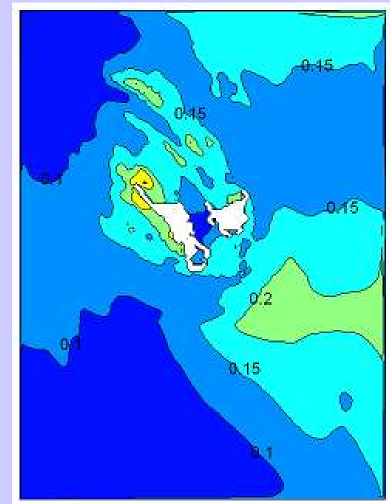
# Comparison of downscaling methods

**RMSE between instantaneous significant wave heights from K-model and statistical methods**

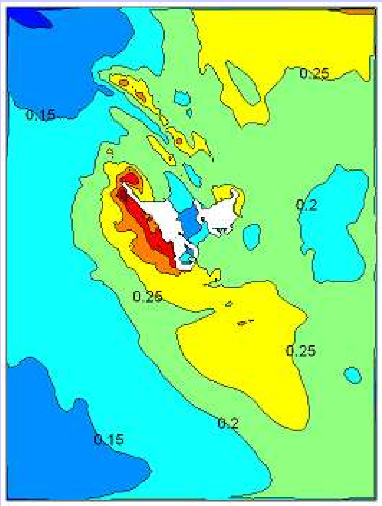
**MLR**




**CCA**



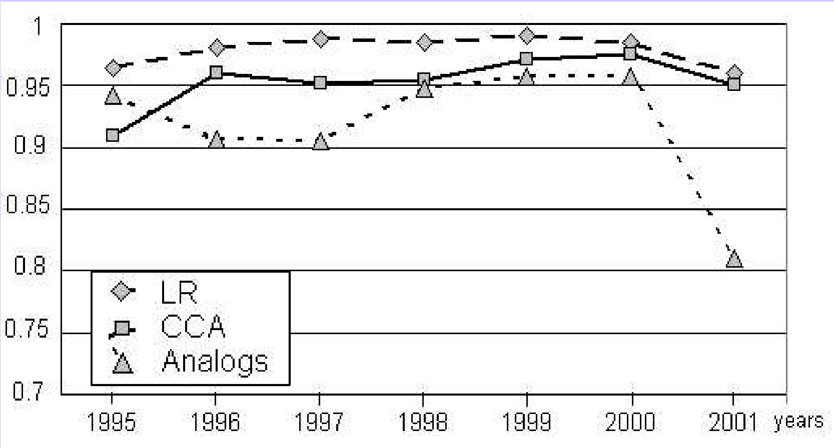

**Analogs**




**Brier skill score for 99%-tiles:**

$$B = 1 - \frac{E((F-P)^2)}{E((R-P)^2)}$$

- F – forecast (downscaling results)
- P – observations (K-model)
- R – reference (HIPOCAS)




**MLR performs best**
**MLR has more parameters than CCA**
**Analogs perform worst, despite 15 000 cases, no analog situations in 2001?**

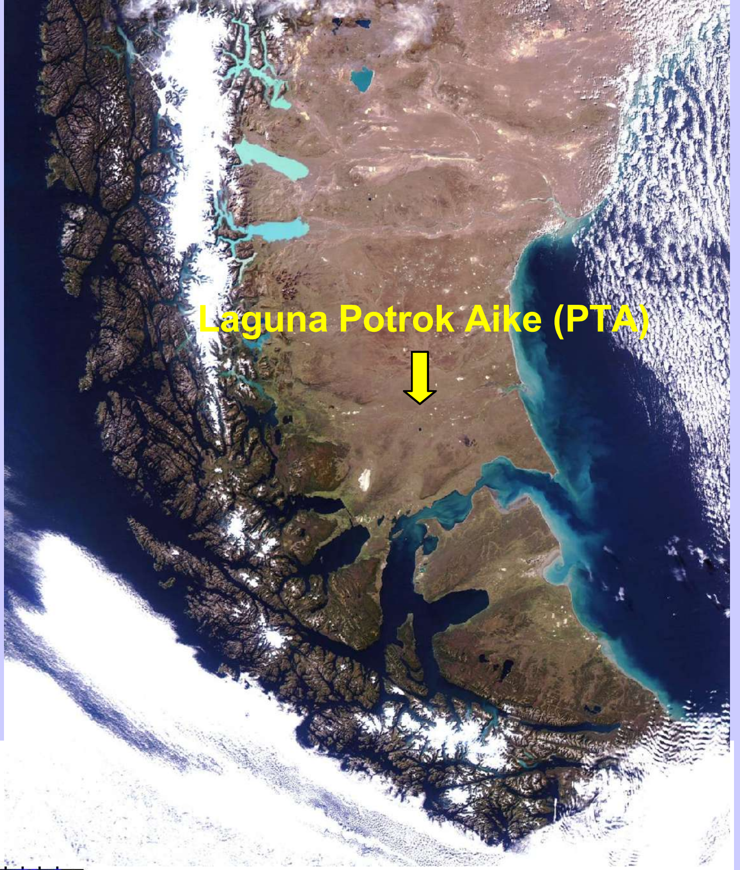
(courtesy Lidia Gaslikova, Ralf Weisse)

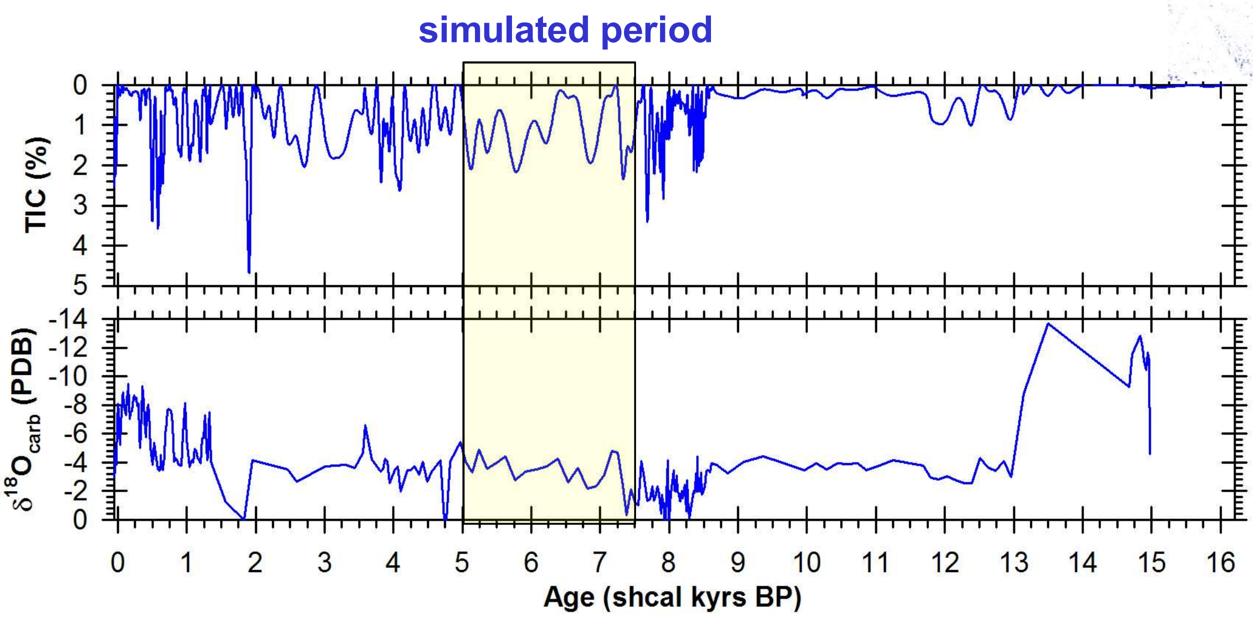
# Mid-Holocene hydrological conditions in southern Patagonia

**Total Inorganic Carbon (TIC) and 18O are proxies for lake level**

**lower lake levels in the Mid-Holocene compared to the pre-industrial period**

**hypothesis: changes are related to the position of the Southern Hemisphere Westerlies**




high

low

lake level

high

low

MIDHOL

Salsa

# ECHO-G

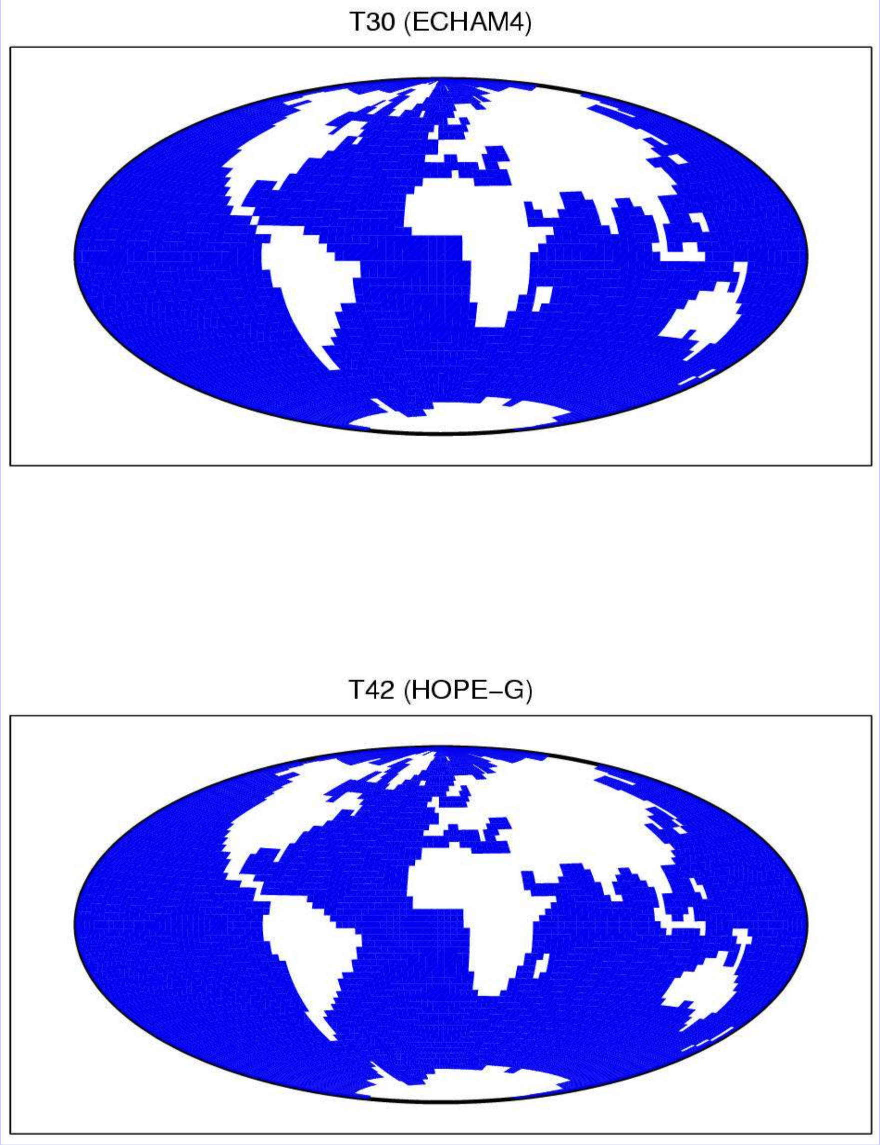
ECHAM4 coupled with HOPE-G

**ECHAM4**

- 19 atmospheric levels
- T30, approx. 3.8 x 3.8 degrees

**HOPE-G**

- 20 ocean levels
- approx. 2.8 x 2.8 degrees
- dynamic-thermodynamic sea-ice model




Simulation speed of ~500 years/month on NEC SX6 8 processors

Model is flux corrected, with prescribed vegetation and land ice

# MIDHOL Model Simulations

MIDHOL

2. Forced Simulation with orbital forcing 7-4.5 ka BP - **ORB**

4. Forced simulation with orbital, solar und greenhouse gas ($CO_2$, $CH_4$,$N_2O$) 7-4.5kyr BP - **ORBSG**

6. Control simulation 7 ka BP - 500 years - internal variability

1. Control simulation 7 ka BP **CON7K** → 2. Orbital forcing

1. Control simulation 7 ka BP **CON7K** → 3. Orbital, solar, greenhouse gas

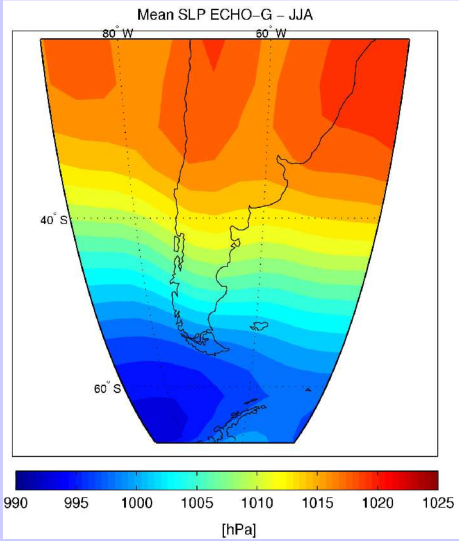
Also: Control simulation with pre-industrial conditions - 300 years – **CONPRE**

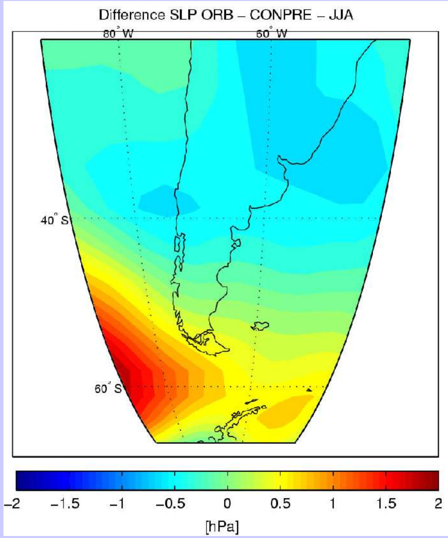
**http://w3k.gkss.de/staff/wagner/midhol.html**

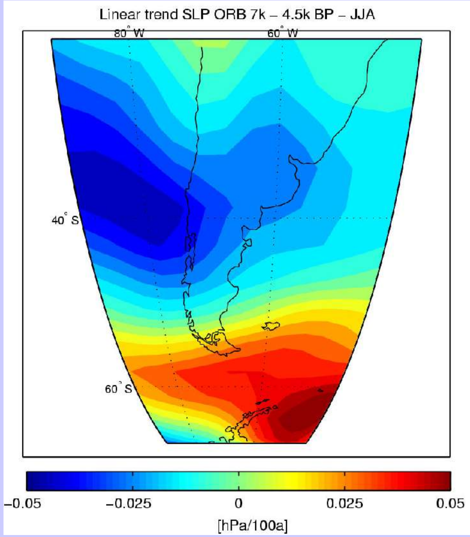
# JJA circulation in ECHO-G

| | Pre-industrial mean | Mid-Holocene - preindustrial | Mid-Holocene trends (7 - 4.5 ky BP) |
|---|---|---|---|

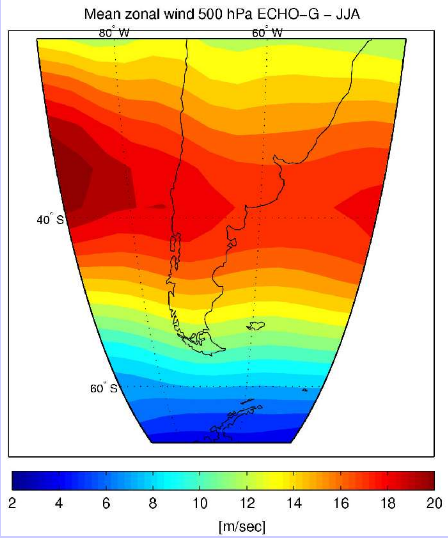
**SLP**

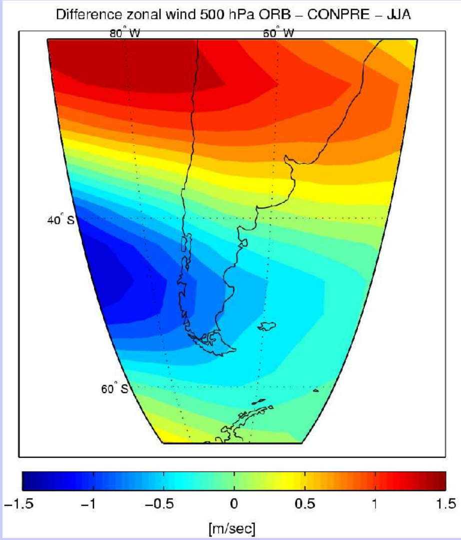


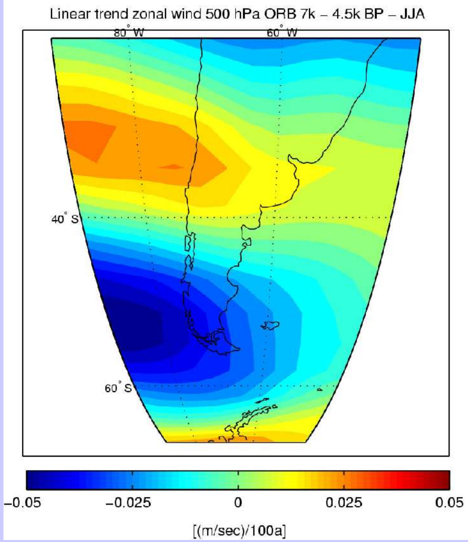




**u500**




(courtesy Sebastian Wagner)

# Downscaling regression weights

**predictand:**
**log of monthly VASCLIMO JJA precip at Potrok Aike**

**final weights from PC-filtered MLR (in $hPa^{-1}$ and $s\ m^{-1}$)**

**upper row: separate models for SLP and u500**

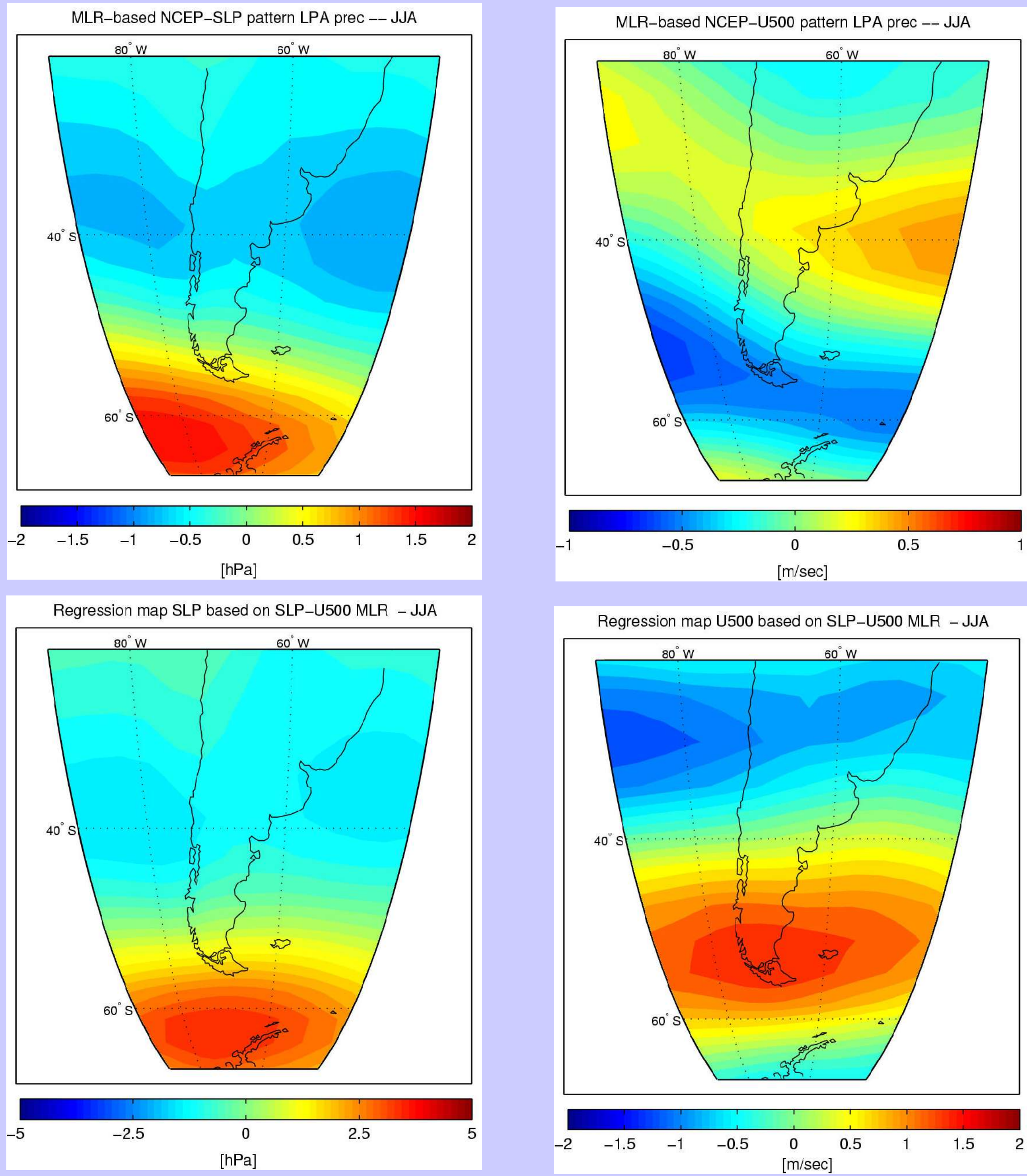
**lower row: SLP and u500 as common predictor**

**skill combined JJA model: r=0.60, RE=0.35**

**[r=0.45, RE=0.19 (DJF)]**

(courtesy Sebastian Wagner)

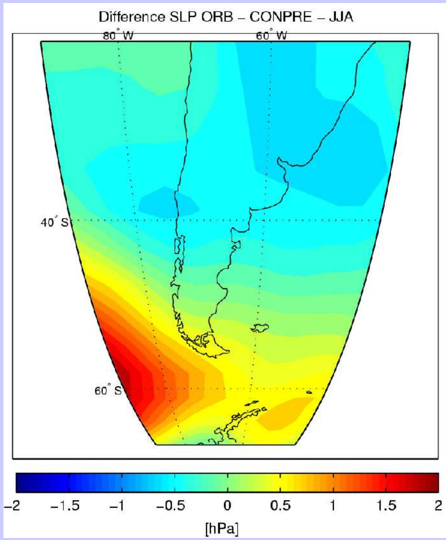
**SLP** **u500**

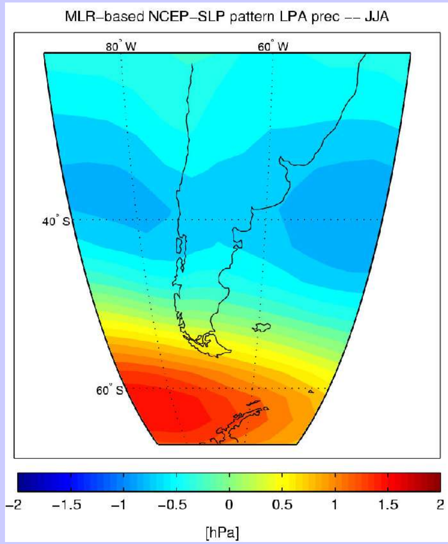


# Mid-Holocene precipitation at Laguna Potrok Aike from DS

## SLP

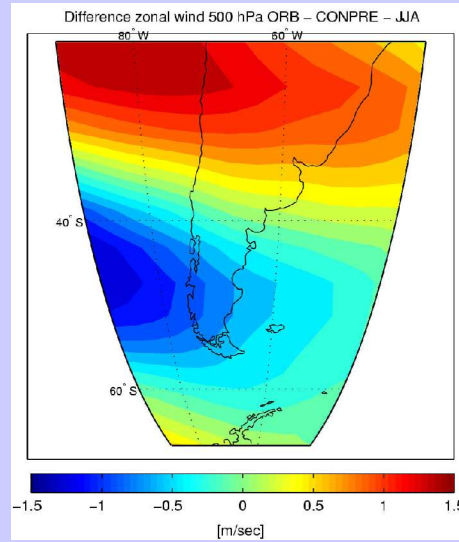
**Mid-Hol. - preindust.** **regression weights**

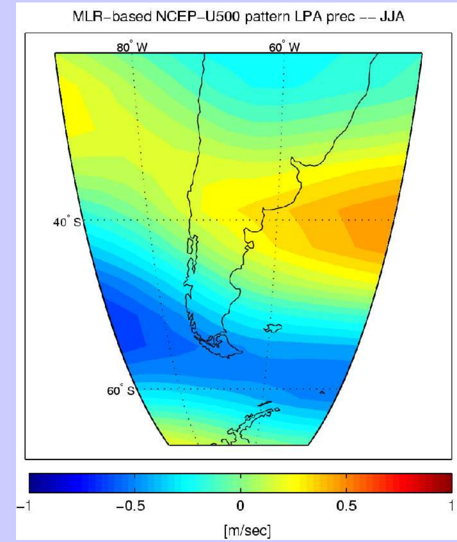


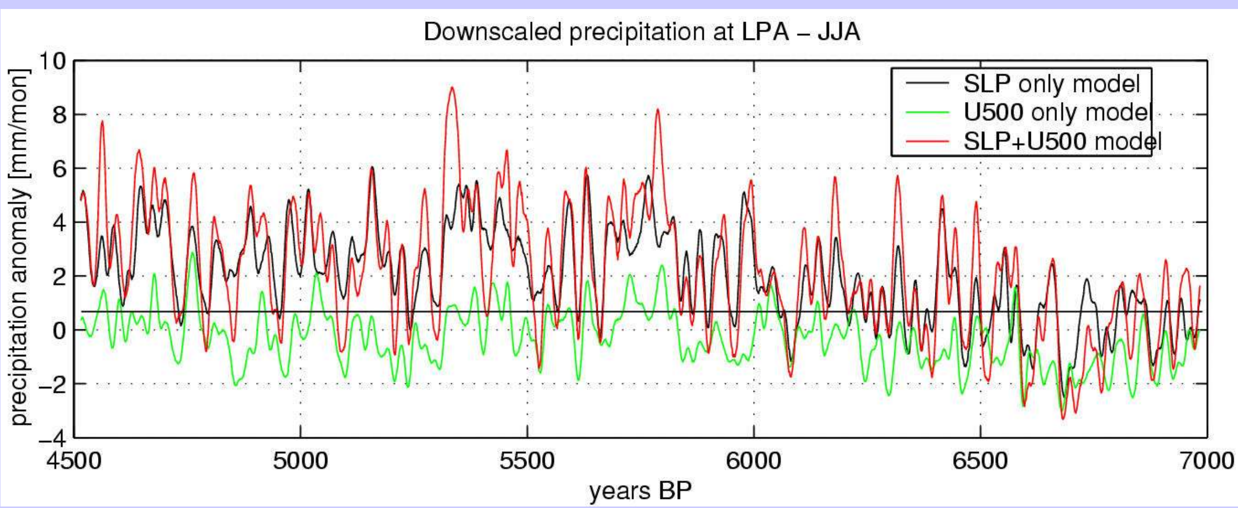




## u500

**Mid-Hol. - preindust.** **regression weights**




(courtesy Sebastian Wagner)

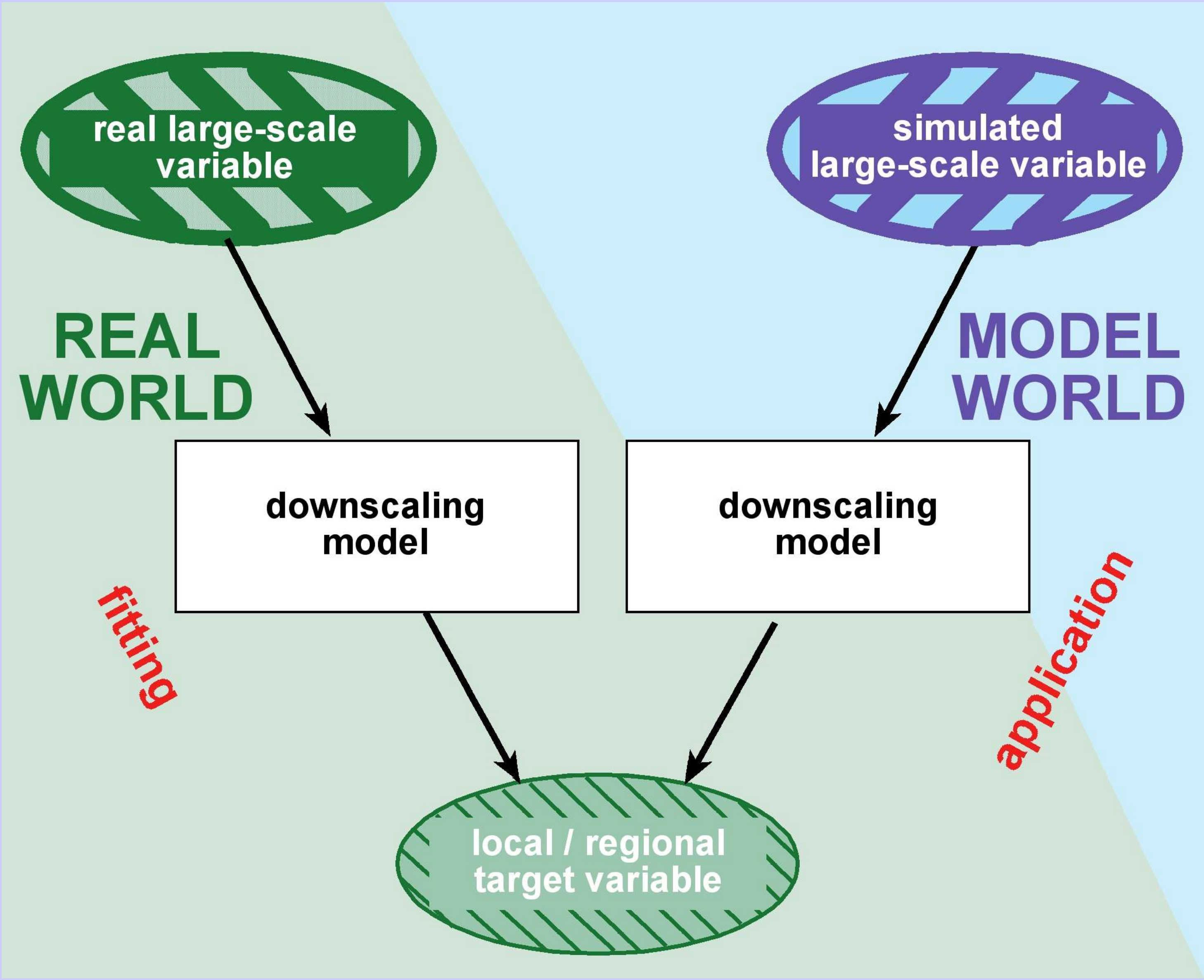
**est. precip model-dependent**

**JJA not consistent with proxies**

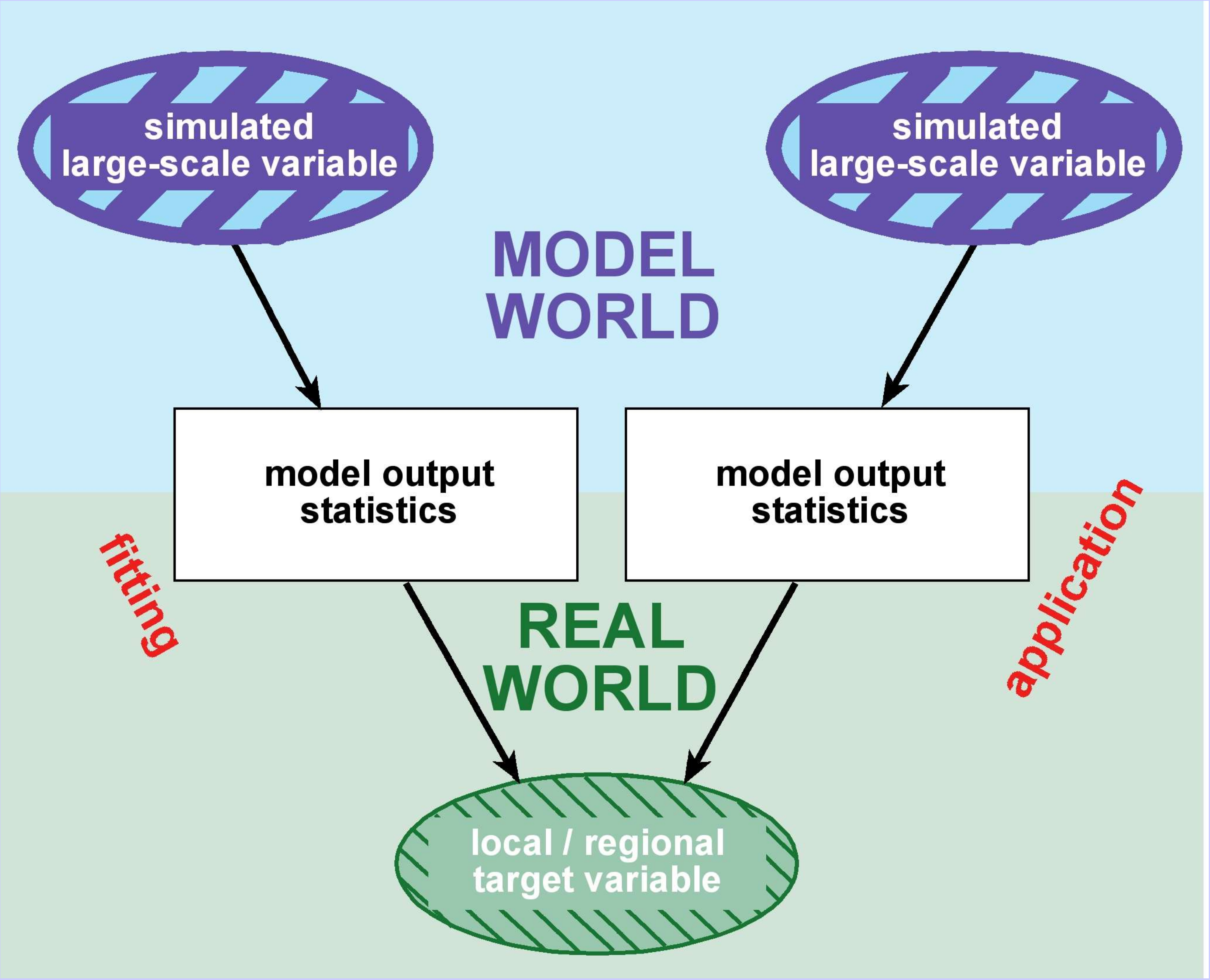
**influence of areas that may not be physically linked to predictand**

**weights may be affected by interannual teleconections**

# **Perfect Prog**(nosis) **Downscaling**



# Model Output Statistics (MOS)



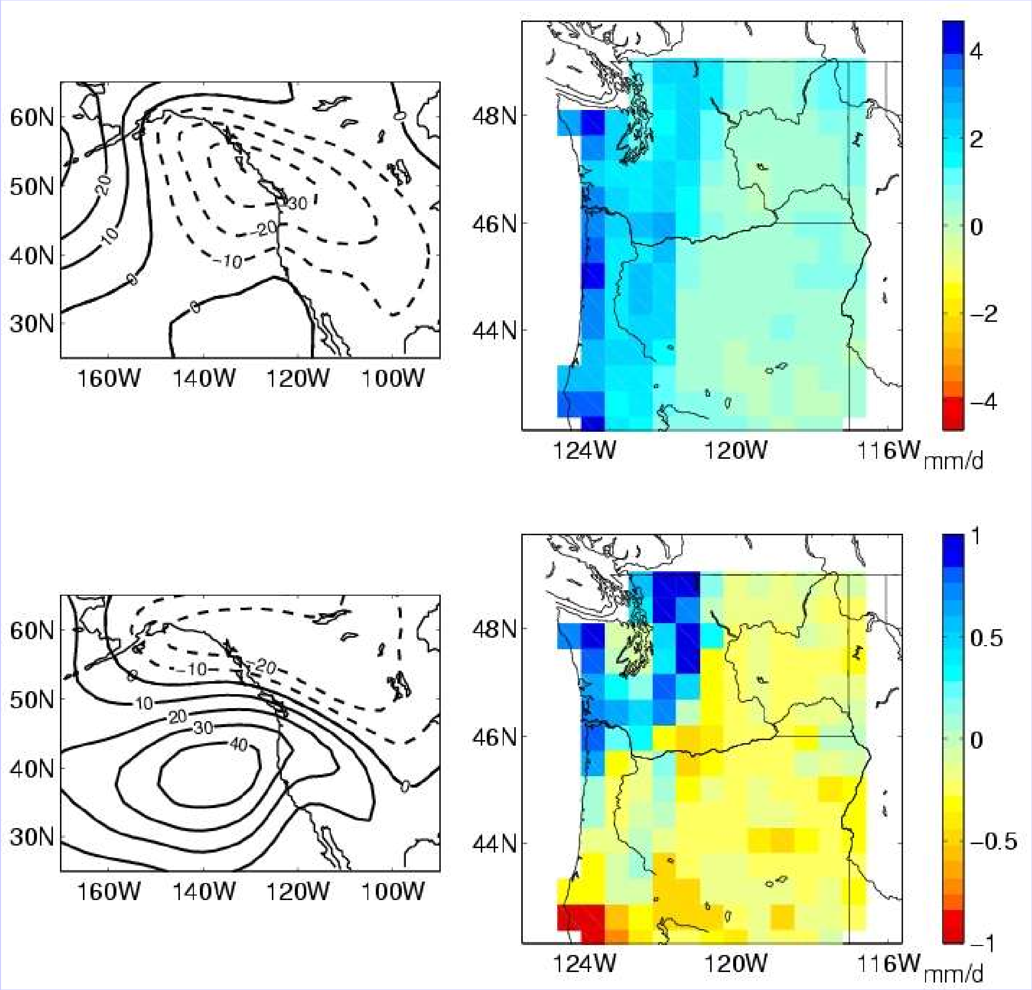
# Coupled anomaly patterns (SVD) between DJF pressure (Z1000, NCEP) and daily precipitation (Perfect Prog downscaling)

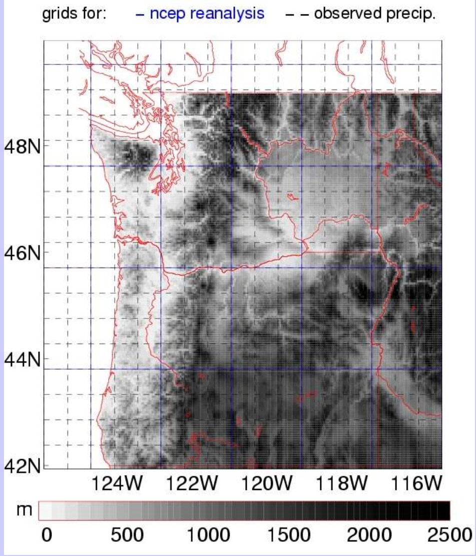
geopot. height (Z1000) precipitation

topography

pair 1

pair 2



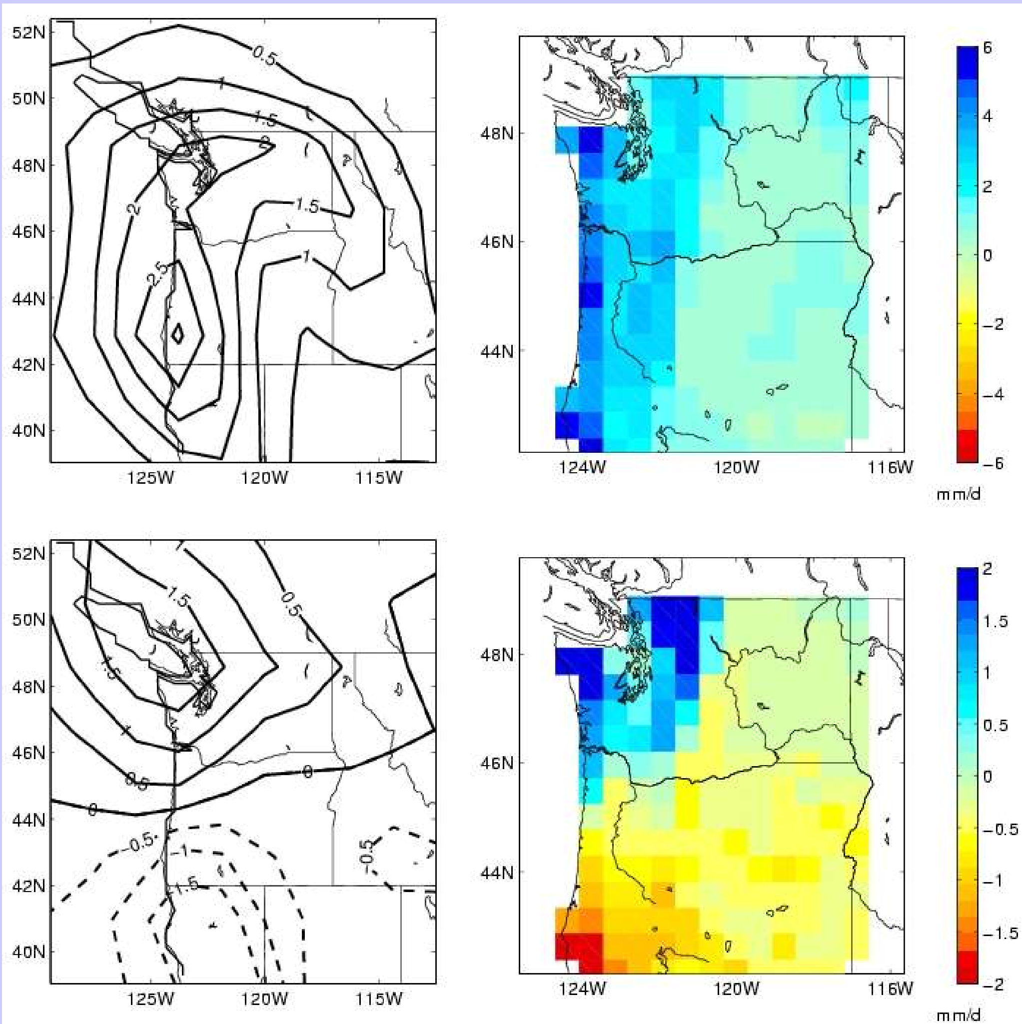



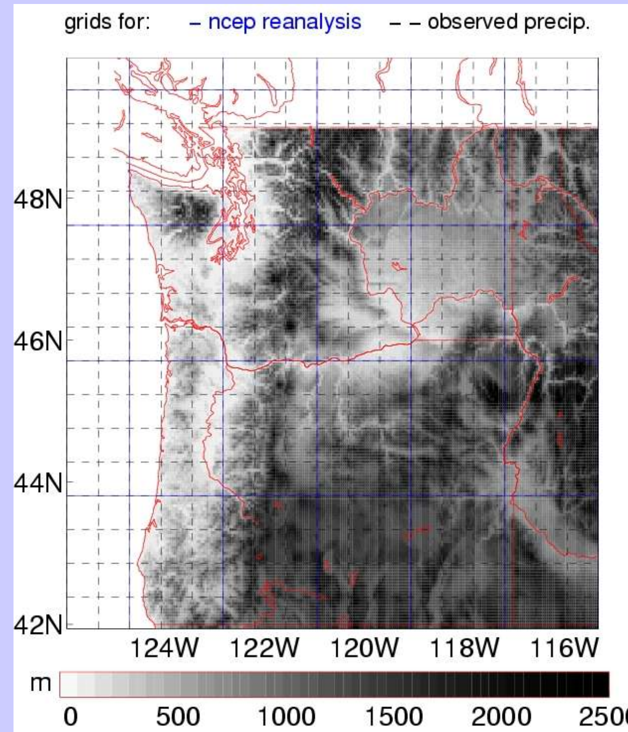

**(Widmann and Bretherton, J. Climate 2000, Widmann et al., J. Climate, 2003)**

# Coupled anomaly patterns (SVD) between simulated (NCEP) and observed daily precipitation (DJF)

simulated precipitation
(NCEP reanalysis)

observations

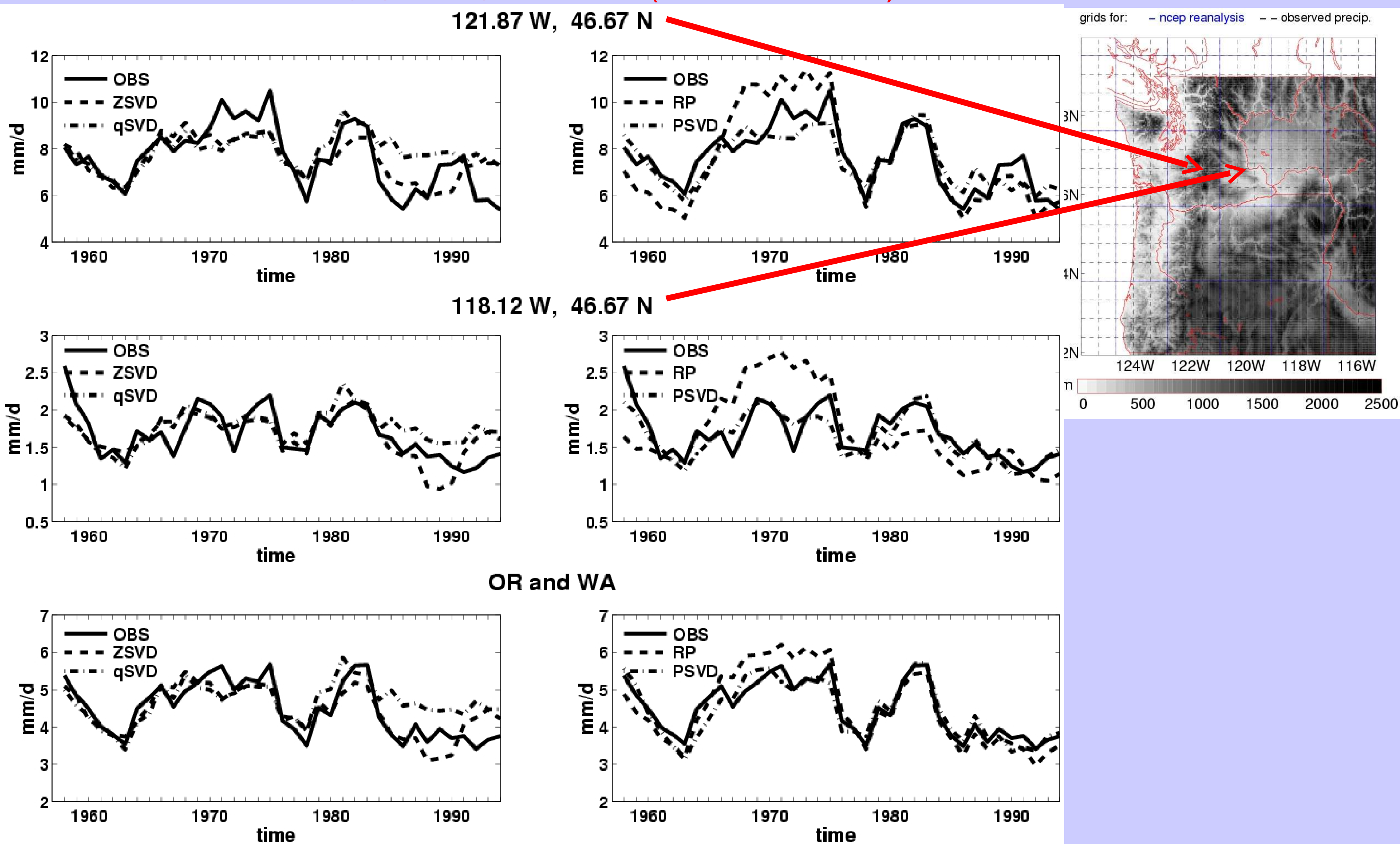


# precipitation (3 y mean, DJF 1958-1998)

predictors: geopot. height (ZSVD) or humidity (qSVD)

simulated precipitation (RP and PSVD)



# MOS applications and requirements

widely used in weather forecasting and partly in seasonal forecasting

potential advantages

- smaller danger of not taking relevant predictors into account

- the statistical model may be simpler, as many processes are still simulated rather than statistically modelled.

- extreme values may be better represented

challenge for application for future climate change and paleo application is the model fitting. One needs:

- GCM simulation in reanalysis mode

- or GCM simulation nudged towards reanalysis circulation states (nudging modules exist for ECHAM4/5)

- how stable are the relationships? (new issue if MOS is applied to long time scales)

# Lessons and questions

## DS for North Sea waves

individual regression for each grid cell work better than CCA and analogs

large number of model parameters seems beneficial and does in this case not lead to overfitting (what‘s the advantage of pattern-based methods?)

## DS for Patagonia precipitation

DS is crucial in paleclimatology for proxy-model consistency test

results are strongly model-dependent, but a smaller predictor area makes them stable (new results, not shown)

large predictor area can be problematic, because it increases the chance that predictor teleconections that are not relevant for the downscaling problem affect the regression weights (overfitting, or time-scale dependent teleconnections)

## MOS for climate change and paleo simulations

large potential for improvement

we need historic GCM simulations for fitting (nudged towards reanalyses)