PROJECTION OF FUTURE DROUGHT CONDITIONS USING DROUGHT INDICES APPLIED TO GCM-SIMULATED WEATHER SERIES

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Introduction

Various drought indices are commonly used to assess drought conditions. In addition to the 12- months Standardized Precipitation Index (SPI) and the Palmer Drought Severity Index (PDSI), the present contribution employs Z-index, which is closely related to PDSI but does not account for the persistence - it rather characterizes the immediate (for a given week or month) conditions. While the SPI is based solely on precipitation data, the PDSI and Z indices are based on precipitation and temperature data and on the available water content of the soil. For climate change impact studies, we consider PDSI and Z to be better indicators as they account for the changes in both temperature and precipitation.

The three indices are calculated by computer programs available from the National Drought Mitigation Center and Computer Science and Engineering, both located at the University of Nebraska-Lincoln. To allow assessment of the climate change impacts, we made the modification of the programs and developed the ***relative drought indices*** [see the box]: these indices are calibrated using the present climate weather series and then applied to the future climate weather series. In assessing impacts of climate change on the drought conditions, we analyze changes in the values of the indices and in the frequency of months belonging to ***drought spells*** [see the definition in the Drought Spells box].

The drought indices are derived from the grid-related GCM-simulated (whole globe) surface monthly weather series for 1991-2020 (present climate) and 2070-2099 (changed climate). To account for the inter-GCM uncertainties, multiple GCM simulations available from the IPCC database are used. The stress is put on Europe and North America.

Drought Indices

SPI = standardized precipitation sum over a given period (**various time-scales**; 1-24 month aggregations are commonly used; 12month SPI is used here). **Gamma distribution** was used here to approximate precipitation sums distribution
input: **precipitation** (various time-scales)

PDSI (Palmer, 1965) is based on a soil moisture/water balance model
input: - **precipitation and temperature** (monthly, weekly)
- **available soil water content** (1 parameter) + latitude
"self-calibrated" index → 2[nd] / 98[th] percentiles = -4.00 / +4.00

Z-index is the key component of PDSI calculations. It describes the water balance value using the same scale **as the PDSI, but for each month irrespective of the water balance status in preceding periods.**
input: - **precipitation** and **temperature** (monthly, weekly)
- **available soil water content** (1 parameter) + latitude

Relative Drought Indices

Self-calibrated SPI, PDSI (classical versions of indices) are applied on the same series that are used to calibrate them
⇒ the PDFs of indices are about the same for each input series
⇒ **and therefore one can hardly use these indices to study the impact of climate change, or to make a between-station comparison of drought conditions**

Relative SPI, PDSI: indices are calibrated using a "learning" series (reference station or reference period), which is generally different from the application series

The relative drought indices allow:

- **between-station comparison of drought conditions**
  - learning series = reference station
  - test series = other station to be compared with the reference station
- **assessing impact of the climate change on a specific station**
  - learning series = present climate series
  - test series = future climate series

Drought Spells

Definition: drought spell is a continuous period with
SPI: (SPI ≤ 0) and (SPI_{min} ≤ -1)
PDSI and **Z-index:** (PDSI ≤ -1) and ($PDSI_{min}$ ≤ -3) or (Z ≤ -1) and (Z_{min} ≤ -3)

The present analysis is based on
- average value of the indices [Fig.3a /Z-ind/; Fig.4a /PDSI/]
- percentage of months within drought spells [Fig.2 /SPI-12/; Fig.3b /Z-ind; Fig.4b /PDSI/]

Other characteristics of drought spells (not used here): duration, accumulated intensity [SUM(X), X = drought index], average intensity, maximum intensity

Present experiment

Time series of three relative indices (SPI-12 /12month SPI/, Z-index, PDSI) are calculated from monthly series of surface temperature and precipitation simulated by 7 GCMs available from the IPCC - Third Assessment Report.

learning (= calibration) period = 1991-2020 (~ present climate)
application period = 2070 - 2099 (~ future climate)

climate change scenarios according to the 7 GCMs are shown in Fig.1

Fig.2: Impact of Climate Change on SPI

[PREC↘] ⇨ [SPI↘] ⇨ [#(dry months)↗]
[PREC↗] ⇨ [SPI↗] ⇨ [#(dry months)↘]

Fig.3-4: Impact of Climate Change on PDSI and Z-index

[PREC↘] + [TEMP↗] ⇨ [PDSI ↘↘] ⇨ [#(dry months) ↗↗]
[PREC↘] + [TEMP↘] ⇨ [PDSI ↘OR↗] ⇨ [#(dry months) ↗OR↘]
[PREC↗] + [TEMP↗] ⇨ [PDSI ↘OR↗] ⇨ [#(dry months) ↗OR↘]
[PREC↗] + [TEMP↘] ⇨ [PDSI ↗↗] ⇨ [#(dry months) ↘↘]

Results

Climate change scenarios differ for individual GCMs [Fig.1]:

temperature: a) winter: in **N.America**, temperature rise increases towards N and NE; in **Europe**, evenly distributed temperature changes are indicated by most GCMs. Only HadCM3 and NCAR show increased temperature rise towards North-East. **b) summer:** Larger between-model differences are found: e.g., spatially evenly distributed changes are prognosed by NCAR and GFDL; CSIRO, CGCM and CCSR/NIES suggest largest temperature rise in NW and NE parts of N.America; HadCM3 prognoses largest (of all GCMs) temperature rise in Central U.S. and Southern Europe

precipitation: a) winter: for **N.America**, precipitation will increase in its northern parts according to most GCMs; however, CGCM and GFDL project highest increase in SW or South U.S. More complicated situation appears to be in **Europe**: CGCM, HadCM and CCSR/NIES prognose largest precipitation increase in NE Europe, CSIRO in SE Europe, ECHAM and NCAR in NE and SW parts of Europe. **b) summer:** rather large between-model differences are found in **N.America**. General trend towards decreasing precipitation in central U.S. and increases on the N.American coasts (Alaska, East, South-West). **Europe:** some increases in its NE part and decreases in south. This pattern is most significantly exhibited in HadCM and to a lesser extent in NCAR model. GFDL projects increase in precipitation in NE, W and SE parts of Europe, with insignificant changes elsewhere.

Relative drought indices in assessing climate change impacts:

SPI-12 changes [Fig.2] follow the annual precipitation changes [Fig.1a]. **N.America**: According to most GCMs, the SPI-12-based drought risk will decrease in northern regions, several models prognose drought increase along Gulf Coast and Central U.S., NCAR indicates drought increase in western U.S. In **Europe**, the GCMs (except for CSIRO) show following trends: drought risk will increase towards south and decrease towards north.

PDSI and Z-index [Figs.3-4] also account for temperature (***thus we consider them more effective in studying climate change impacts!***), which is projected to rise in most parts of the world. Therefore, the areas with increased drought stress (under a changed climate) as indicated by PDSI and Z-index changes are larger than the areas indicated by SPI changes. Except for the northmost part of N.America, drought risk will increase. In Europe, this increase is most significantly exhibited in its southern and eastern regions. Z-index indicates that the drought stress will increase mostly in summer. In winter, only CCSR/NIES shows significant increase in winter drought stress in Central U.S. and along Mediterranean coast. Except for few regions in some GCMs (SW coast of U.S. in CGCM, northern part of N.America in NCAR and HadCM /to a lesser extent/), the PDSI-based drought risk will increase in all parts of Northern America and Europe (PDSI maps are shown only for annual values, as PDSI climatology exhibits insignificant annual cycle)

Results of our drought studies were presented also during other conferences:
- http://www.ufa.cas.cz/dub/impacts/2005-egu-drought.pdf (EGU conference, 2005, Vienna)
- http://www.ufa.cas.cz/dub/impacts/2005-ems-drought.pdf (EMS conference, 2005, Utrecht)
- http://www.ufa.cas.cz/dub/impacts/2005-agu-drought.pdf (AGU fall meeting, 2005, San Francisco)

This poster is also available on web: **http://www.ufa.cas.cz/dub/impacts/2006-longmont-drought.pdf**

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Global Climate Model	Fig.1 Climate change scenario (2070-2099) wrt ((1991-2020)			Fig.2 Relative SPI-12 (calibration period = 1991-2020)
	a) Annual **top:** Temperature [°C] **bottom:** Precipitation [%]	**b) Winter (=DJF)** **top:** Temperature [°C] **bottom:** Precipitation [%]	**c) Summer (=JJA)** **top:** Temperature [°C] **bottom:** Precipitation [%]	**#months within drought spell [%]** **present:** 1991-2020 **future:** 2070-2099

CSIRO-Mk2:

CGCM2:

ECHAM4/ OPYC3:

GFDL-R30:

HadCM3:

CCSR/NIES:

NCAR-PCM:

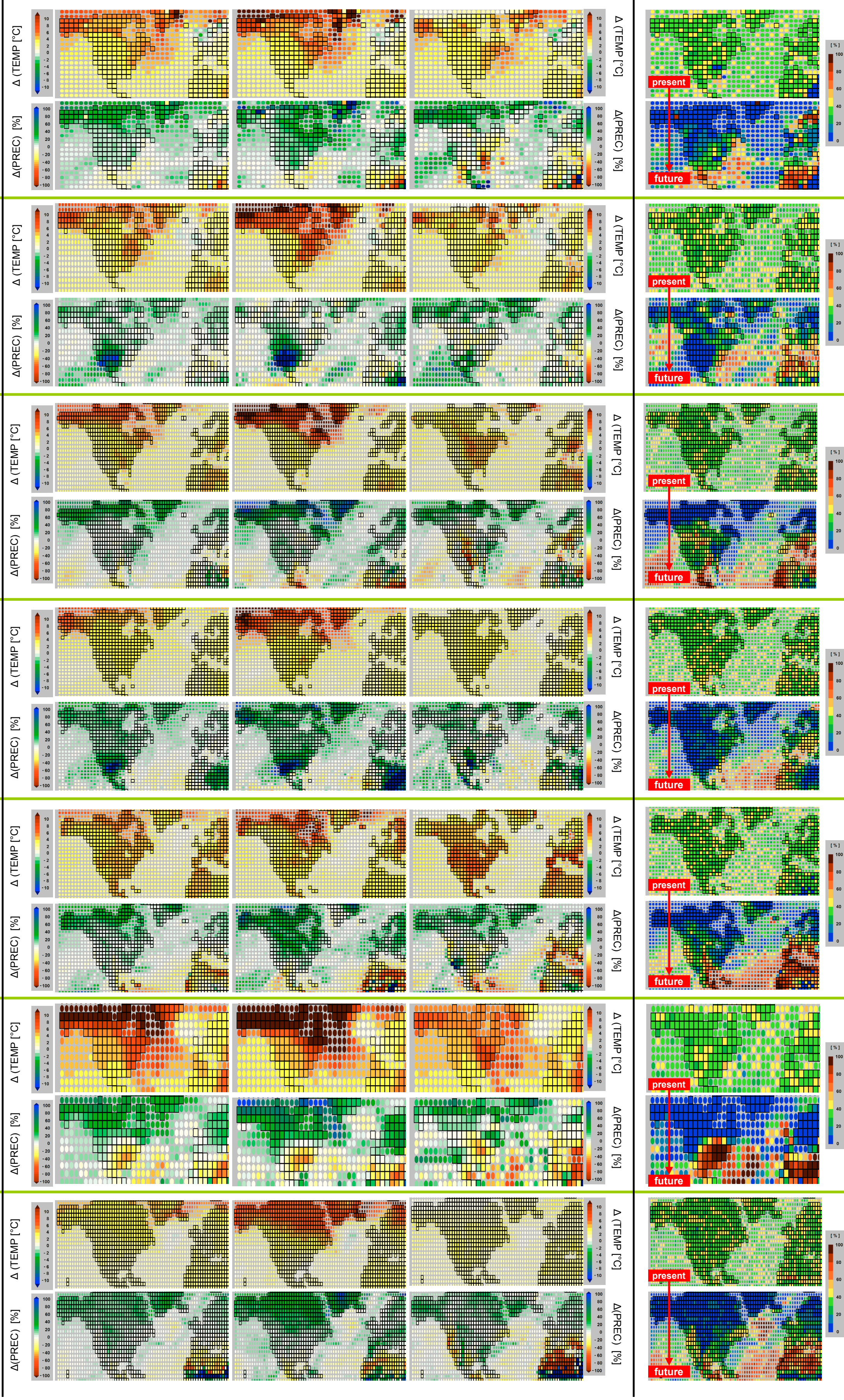

Fig.3 Relative Z-index
(calibration period = 1991-2020)

Fig.4 Relative PDSI
(calibration period = 1991-2020)