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Multi-scalar drought and its impact on crop yield in the Republic of Moldova

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Abstract

The crop loss due to drought is a complex issue, because it changes according to drought intensity and duration, and plant's developmental stage during which drought occurs. In order to assess the drought-induced decline in crop harvest, first we investigated drought variability and the yield sensitivity to drought of winter wheat, maize, sugar beet, and sunflower during their growing seasons in the Republic of Moldova as a model example of a non-irrigated crops response to increasing drought tendency in the southern-east Europe.

The quantification of drought was done by using the Standardized Precipitation Evapotranspiration Index (SPEI) at 1 to 12-month lags during the period 1951-2012.

The relationship between the drought at various time scales and the Standardized Yield Residuals Series (SYRS) for individual crop over the country and Balti chernozem steppe of Moldova for the farming years 1962-2012 were investigated.

The SPEI highlights the main periods of dry and wet persistence and the regional characteristics of drought which present the Southern region more prone to severe drought persistence, mostly during the last decade.

Drought during reproductive stages may significantly reduce the grain yield potentials, which the SPEI can explain up to 62% of the low-yield variability. The results of the non-parametric tests show downward shifts (increasing yield losses), significant at 99% level, in the SYRS of all crops with most of the change point years in the 1990´s.

Introduction

- Agriculture is one of the most climate-sensitive of all economic sectors. In many countries, such as in Moldova, the risks of climate change are an immediate and fundamental problem because the majority of rural population depends either directly or indirectly on agriculture for their livelihoods.
- Drought is one of the most severe natural hazard causing important environmental constraints limiting plant growth, development and crop yield with tremendous economic and societal impacts. It is a multidimensional stress affecting plants at various levels of their organization.
- The effect of and plant response to drought at the whole plant and crop level is most complex because it reflects the integration of stress effects and responses at all underlying levels of organization over space and time.
- The increase in drought frequency may neutralize the expected positive effects of a longer growing season and may decrease the effectives of "typical drought mitigation strategies".
- When precipitation deficiency spans an extended period of time (i.e., meteorological drought), its existence is defined initially in terms of these natural characteristics. However, the other common drought types (i.e., agricultural, hydrological, and socioeconomic) place greater emphasis on social aspects of drought and the management of natural resources.
- In the Republic of Moldova (RM), the main natural factors that determine high and stable crop yields are timely rainfall and soil fertility. Soil is the main natural resource of the RM.
- However, the fragmentation of land holdings through land reforms has accelerated loss of soil organic matter (Boincean, 2014). Consequently, changes in soil structure are synchronized with changes in soil moisture.

Material and methods

Meteorological data and drought identification:

- The meteorological stations were classified in the three agro-climatic regions: North, Central and South, whilst Balti is the meteorological station located near the experimental fields of RIFC (Selectia Research Institute of Field Crops) (Fig. 1).
- In this study, we updated the time series of monthly precipitation (P), minimum (tmin) and maximum (tmax) air temperatures at 15 meteorological stations for the period 1951-2012. These data were used to calculate the potential evapotranspiration (PET) with the Hargreaves method (Hargreaves and Allen, 2003) and the SPEI (Vicente-Serrano et al., 2010).
- A detailed comparison between two empirical methods for calculating PET, namely Hargreaves and Penman-Monteith in the RM can be found in Potop and Boroneat (2014).
- The results confirm, that Hargreaves method can be used as an acceptable alternative to Penman-Monteith method to estimate PET.
- We utilised the performance of the multi-scalar SPEI in evaluating the accumulative moisture condition from the sowing to the harvest period of crops. Duration of drought was calculated as the number of months from the first month when SPEI value was lower than − 1 to the last month with a negative value before the index turned back positive.
- Drought severity stands for the number of months in which the drought indicator at various lags was lower than – 1 (Table 1a).

Yield data:

- The annual series of crop yield of winter wheat, maize, sugar beet, and sunflower at national level as reported by the National Bureau of Statistics of the Republic of Moldova during the period 1962-2012 were used to assess the crop sensitivity to drought as quantified by the SPEI at 1 to 12-month lags for each month of the growing season. Additionally, the high-quality crop yield experimental data on Typical chernozem in the Balti steppe of Moldova, available from the RIFC were compared with the national yield series.
- Yield series were de-trended using a quadratic trend as the most suitable method according to the minimal mean absolute percentage error. The indicator of agricultural
- drought risk may be represented by the residuals of the de-trended yield.
- To compare yield variability among the crops with different means and standard deviations, the series of were standardized for each crop using the Z-score transformation and obtained Standardized Yield Residuals Series (SYRS) (Fig. 2, Table 1b).
- The correlation coefficients between the time series of low-yielding years (SYRS≤-0.5) and drought (SPEI≤-1) for 1 to 12-month lags were calculated.

Results and discussion

- Hovmoller-type diagrams were generated to provide a visualisation of the spatiotemporal evolution of the SPEI calculated for each month of the year at 1 to 48 month lags for the three agro-climatic regions and near the RIFC at Balti (**Fig. 3**).
- **Figure 4** shows the temporal evolution and the quadratic trend of yield crops at national level and at the experimental fields. According to converted yield residuals into the standardized values, the number of low-yielding years (SYRS≤–0.51) at country level (chernozem steppe) for the winter wheat was 16 (12), for maize was 12 (8), for sunflower was 13 (12), and sugar beet was 14 (11).
- **Figure 5** suggests that inter-annual variation in the SYRS of overwintering and summer crops over the country during 1994 to 2007 show strong negative anomaly.
- The results of polynomial regression analysis show big differences in the responses of crops growing under optimal agro-technological experimental conditions (rotations and fertilization) and national yields (series resulting from averages yield at all farms) (**Fig. 6**).
- The correlation coefficients between the SPEI≤-1 and SYRS≤-0.51 for the long-term field experiments were significantly smaller than for the national yields. This result can be explained by the fact that (1) yield under crop rotations and fertilization are more efficient water harvesters; (2) crops of the long-term field experiments have less low-yielding years than at country level; (3) Typical chernozem of the Balti steppe under field experiments is more resistant to drought and able to cope better with less and more erratic rainfall.
- The yield losses were expressed in relative terms (loss in %) for an individual crop and year averaged at country level (**Table 2 and 3**).

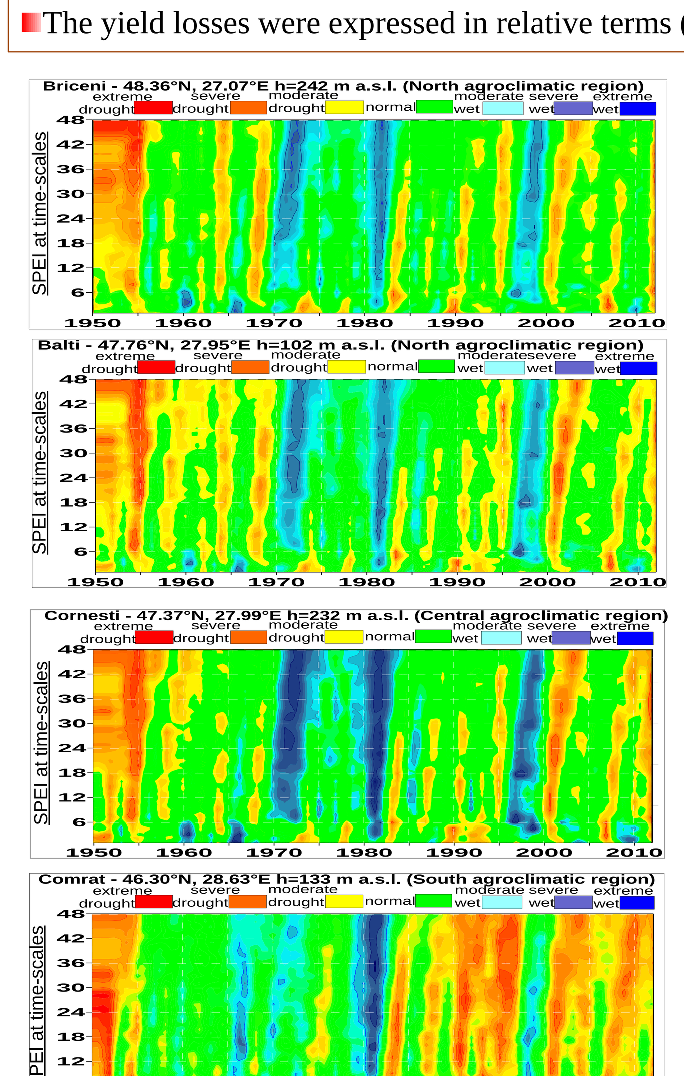

Fig. 3 Spatiotemporal evolution of drought (wettness) development from 1 to 48-month lags per regions.

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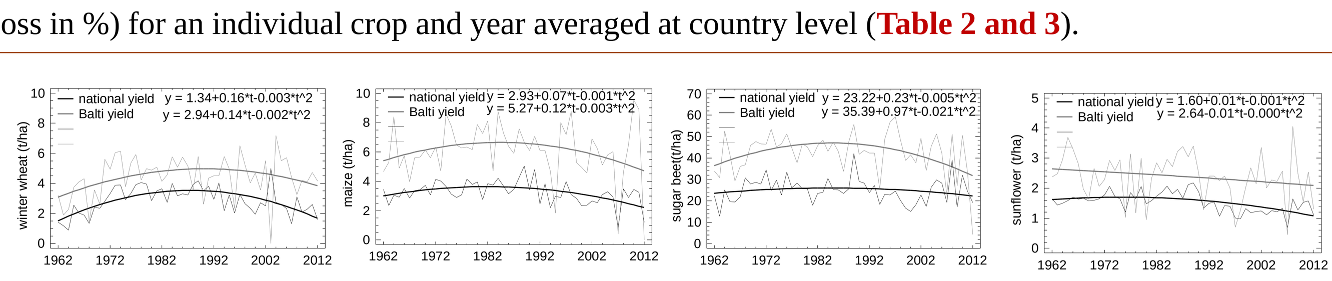


Fig. 4 Temporal evolution and quadratic trend of the yield crops series for the Republic of Moldova and Balti chernozem steppe during the farming years 1962-2012.

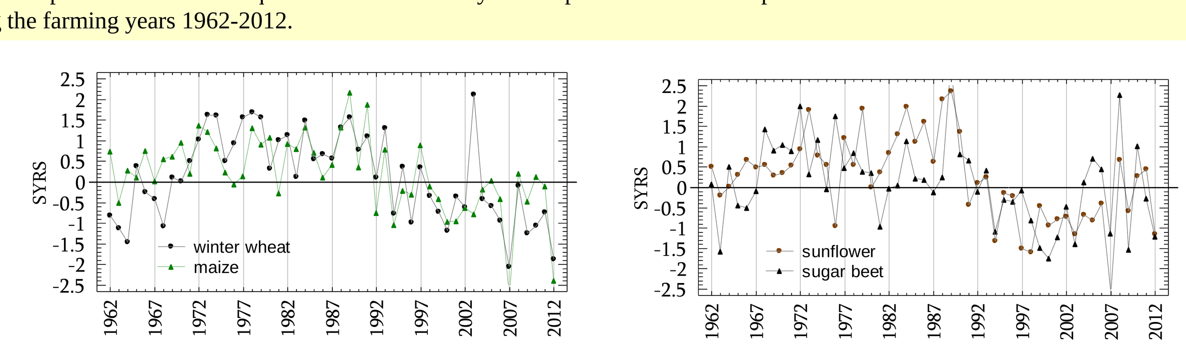


Fig. 5 Temporal variability of the SYRS for winter wheat, maize, sunflower and sugar beet at the country level during the farming years 1962-2012.

Conclusions

- From early to mid-grain filling of winter wheat (June) when young developing grains can be aborted due to a lack of assimilate, a moderate correlation at the SPEI time lags from 3 to 4-months was observed.
- The SYRS of maize yield has a higher correlation with the SPEI than winter wheat, i.e. maize production is a more affected by drought.
- Sunflower being an oil seed crop, it is particularly susceptible to water shortage at flowering (June, *r = 0.40* from 3 to 6-month lags) and grain fill (July, *r = 0.24 to 0.43* from 1 to 6-month lags) stages.
- A significant correlation was observed between the SYRS of sugar beet and SPEI at time scales from 4 to 7 months during September and October (*r = 0.50*)
- Experimental data demonstrates that greater crop diversity lead to more drought-resilient, where organic matter increases the pore space in the soil, where water can be held more easily, making the soil capable of storing more water during a longer period and such facilitating infiltration during heavy rains.
- Therefore, building a healthy soil becomes a critical measure in enabling farms to cope with drought. Soil is a major buffer against climate change and the only one that we can manage effectively.

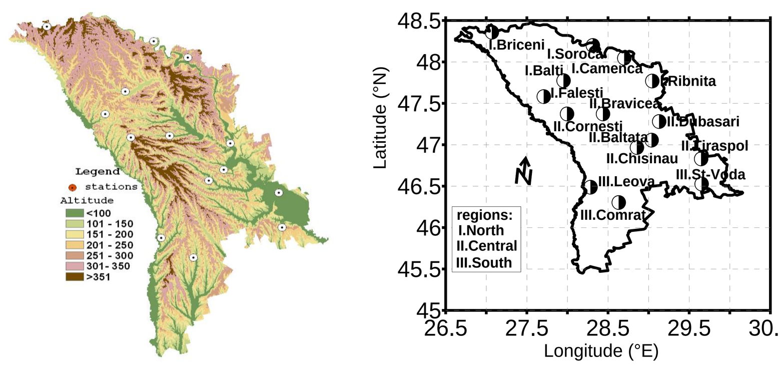


Fig. 1. Map of Republic of Moldova and the distribution of the meteorological stations by agro-climatic regions (I, II, and III refer to North, Central, and South agro-climatic regions).

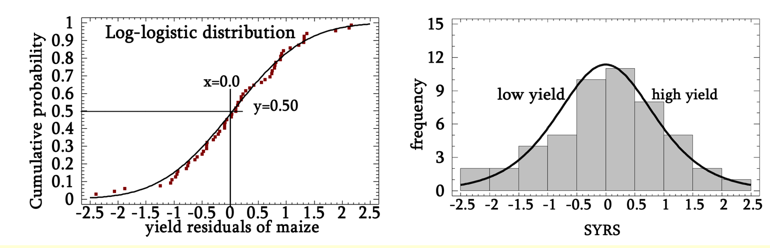


Fig. 2 Quantile plot of differences between the empirical cumulative distribution of yield residuals of maize and the cumulative distribution function of the fitted log-logistic distribution (left). Histogram plot of frequency distribution of the SYRS of maize at the country level during the farming years 1962-2012 (right).

Table 1. Classes of a) moisture categories according to SPEI and b) yield categories according to SYRS (Potopová *et al.*, 2015)

a)

SPEI	Moisture category	Frequency, %
≥2.0	Extreme wet	2
1.50 – 1.99	Severe wet	6
1.49 - 1.00	Moderate wet	10
0.99 - -0.99	Normal	65
-1.00 – -1.49	Moderate drought	10
-1.50 - -1.99	Severe drought	5
≤-2.00	Extreme drought	2

b)

SYRS	Yield category	Frequency, %
≥ 1.50	High yield increment	2.3
1.00 –1.49	Moderate yield increment	4.4
0.51 – 0.99	Low yield increment	9.2
0.50 – -0.50	Normal	68.2
-0.51 – -0.99	Low yield losses	9.2
-1.00 – -1.49	Moderate yield losses	4.4
≤ -1.50	High yield losses	2.3

Table 2. Quantification of the yield crop losses due to drought impact (SPEI-3≤ -1.0) during the main crop stages at the country level for the farming years 1962-2012

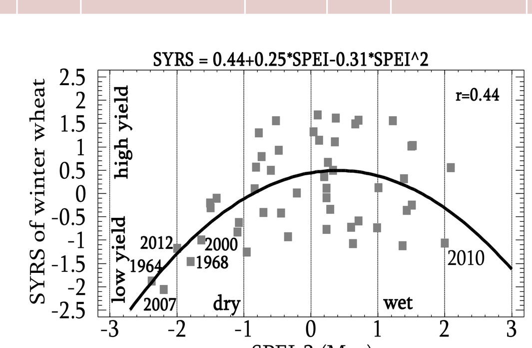
	Winter wheat		Maize		Sunflower		Sugar beet	
	Frequency of drought, %	Yield losses, (%)	Frequency of drought, %	Yield losses, (%)	Frequency of drought, %	Yield losses, (%)	Frequency of drought, %	Yield losses, (%)
Sowing	22.6	9.9	19.4	8.8	17.7	6.1	19.4	7.9
Risk period	17.7	18.8	24.3	30.5	22.6	22.3	24.2	27.2
Harvest	24.2	2.3	17.8	5.8	19.4	1.5	16.1	3.6

Table 3. Percentage of yield crop losses (Y, %) due to severe drought/wet occurrences in the main productive crop stages at national level

Winter wheat			Maize			Sunflower			Sugar beet		
year	Y (%)	stages*	year	Y (%)	stages	year	Y (%)	stages	year	Y (%)	stages
2007	-50	Sowing to harvesting	2007	-67	Sowing to harvesting	2007	-54	Sowing to harvesting	1963	-45	Leaves cover 90% of ground
1964	-44	Sowing to booting	2012	-46	Sowing to anthesis	1998	-35	Leaf development	2000	-39	Sowing to harvesting
1968	-43	Flowering	1994	-35	Sowing to harvesting	1997	-33	Sowing to harvesting	1999	-34	Leaves cover 90% of ground (storage root)
2012	-38	Post-flowering to late milk	1992	-30	Beginning of grain development	1994	-29	Sowing to harvesting	1981	-30	Sowing to harvesting
2000	-36	Post-flowering to late milk	2000	-25	Sowing to fully ripe	2012	-27	Flowering to ripening	2003	-28	Sowing to leaves cover 10% of ground
1994	-36	Stem elongation to flowering	1981	-24	Sowing to harvesting	2003	-26	Stem elongation to inflorescenc e emergence	1994	-28	Sowing to harvesting
1963	-29	Sowing	1963	-23	Early dough (kernel content soft)	2000	-21	Sowing to flowering	2001	-26	Leaves cover 40% of ground
1999	-25	Ripening	2001	-22	Dough (about 55% dry matter)				2009	-26	Leaves cover 90% of ground (storage root)

(a) SYRS of winter wheat

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July
SPEI-1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.1	0.4
SPEI-2	0.1	0.1	0.1	0.1	0.1	0	0.2	0.3	0.2	0.3
SPEI-3	0.2	0.2	0.2	0.2	0.2	0	0.2	0.4	0.3	0.3
SPEI-4	0.4	0.1	0.1	0.1	0.1	0.1	0.1	0.4	0.3	0.4
SPEI-5	0.3	0.3	0	0.1	0.1	0.1	0.1	0.2	0.2	0.4
SPEI-6	0.3	0.2	0.1	0.2	0.1	0	0.1	0.1	0.2	0.3
SPEI-7	0.4	0.4	0.1	0.3	0.1	0.1	0.1	0.1	0.1	0.3
SPEI-8	0.4	0.3	0.2	0.2	0.2	0.3	0.2	0.2	0.1	0.2
SPEI-9	0.3	0.3	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2
SPEI-10	0.3	0.3	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.3
SPEI-11	0.3	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3
SPEI-12	0.3	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3



(b) SYRS of maize

	Apr	May	June	July	Aug	Sep	Oct
SPEI-1	0.2	0.2	0.3	0.5	0.2	0.2	0
SPEI-2	0.2	0.3	0.4	0.5	0.5	0.3	0.1
SPEI-3	0.2	0.3	0.4	0.5	0.5	0.5	0.3
SPEI-4	0.1	0.3	0.4	0.5	0.5	0.5	0.5
SPEI-5	0.2	0.2	0.4	0.5	0.5	0.6	0.5
SPEI-6	0.2	0.3	0.3	0.5	0.6	0.6	0.6
SPEI-7	0.2	0.3	0.4	0.4	0.5	0.6	0.6
SPEI-8	0.3	0.3	0.3	0.5	0.5	0.6	0.6
SPEI-9	0.3	0.3	0.3	0.4	0.5	0.5	0.6
SPEI-10	0.3	0.3	0.4	0.4	0.5	0.6	0.5
SPEI-11	0.2	0.4	0.4	0.5	0.5	0.5	0.6
SPEI-12	0.2	0.3	0.4	0.5	0.5	0.5	0.5

(c) SYRS of sunflower

	Apr	May	June	July	Aug	Sep
SPEI-1	0.1	0.1	0.2	0.2	0.4	0.1
SPEI-2	0.1	0.1	0.2	0.2	0.3	0.1
SPEI-3	0.2	0.2	0.4	0.4	0.3	0.3
SPEI-4	0.2	0.2	0.4	0.4	0.4	0.3
SPEI-5	0.2	0.2	0.4	0.4	0.2	0.2
SPEI-6	0.2	0.2	0.4	0.4	0.2	0.3
SPEI-7	0.2	0.2	0.2	0.3	0.2	0.3
SPEI-8	0.3	0.2	0.2	0.3	0.2	0.3
SPEI-9	0.3	0.2	0.2	0.3	0.3	0.3
SPEI-10	0.3	0.3	0.3	0.3	0.2	0.3
SPEI-11	0.3	0.3	0.3	0.3	0.3	0.3
SPEI-12	0.3	0.3	0.3	0.3	0.3	0.3

(d) SYRS of sugar beet

	Apr	May	June	July	Aug	Sep	Oct
SPEI-1	0.1	0.2	0.4	0.4	0.2	0.3	0.1
SPEI-2	0.1	0.2	0.4	0.4	0.4	0.4	0.3
SPEI-3	0.1	0.2	0.5	0.4	0.4	0.5	0.3
SPEI-4	0.1	0.2	0.5	0.4	0.4	0.5	0.5
SPEI-5	0.1	0.1	0.5	0.3	0.4	0.5	0.5
SPEI-6	0.1	0.1	0.5	0.3	0.4	0.5	0.5
SPEI-7	0.1	0.1	0.2	0.2	0.3	0.5	0.5
SPEI-8	0.1	0.1	0.1	0.3	0.3	0.4	0.5
SPEI-9	0.1	0.1	0.1	0.2	0.3	0.4	0.5
SPEI-10	0.1	0.1	0.1	0.2	0.3	0.4	0.4
SPEI-11	0.1	0.1	0.1	0.2	0.3	0.4	0.4
SPEI-12	0.1	0.1	0.1	0.2	0.2	0.3	0.4

r	0.0	0.1	0.2	0.3	0.4	0.5	0.6

Fig. 6 The tables present the correlation coefficients (*r*) between the monthly SPEI at 1 to 12-month lags and the SYRS of winter wheat (a) maize (b), sunflower (c) sugar beet (d) at country level for the period 1962-2012. The graph shows the second-order polynomial regression between the SYRS of winter wheat and the SPEI at 3-mo lag in May (as an example).

REFERENCES

Hargreaves GL, Allen RG. 2003. History and evaluation of Hargreaves evapotranspiration equation. *J. Irrigat. Drain. Eng.* **129:** 53–63, doi.org/10.1061.

Boincean BP. 2014. *Fifty years of field experiments with crop rotations and continuous cultures at the Selectia Research Institute for Field Crops*. In: Dent D. (ed.). Soil as World Heritage. Springer, Dordrecht. 175-200, doi: 10.1007/978-94-007-6187-2

Potop V, Boroneat C. 2014. Assessment of potential evapotranspiration at Chisinau station. In: Rožnovský, J., Litschmann, T., (eds): Mendel a bioklimatologie. Brno, 3. – 5. 9. 2014, 12 s. ISBN 978-80-210-6983-1.

Potopová V, Štěpánek P, Možný M, Türkott, L, Soukup J. 2015. Performance of the standardized precipitation evapotranspiration index at various lags for agricultural drought risk assessment in the Czech Republic. Agric. For. Meteorol. 202: 26-38, doi:10.1016/j.agrformet.2014.11.022.

Vicente-Serrano SM, Beguería S, López-Moreno JI. 2010. A Multi-scalar drought index sensitive to global warming: The Standardized Precipitation Evapotranspiration Index – SPEI. *Journal of Climate*. **23 (7)**: 1696-1718, doi: 10.1175/2009JCLI2909.1.