Regional Contrasts in Soil Dust Emission Responses to Climate

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(On the Web at http://dust.ess.uci.edu/smn/smn_rdb_iamas_2005.pdf)

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Abstract

1. Supply-limited dust emission appears more prevalent than previously thought and is not accounted for in models.
2. In many of Earth's dustiest regions, dust and precipitation anomalies correlate positively, consistent with sediment-supply constraints.
3. Reproducing these wind erodibility responses in models may help remediate underprediction of observed seasonal to interannual dust variability.

1. Aeolian Erodibility

Soil aeolian erodibility S is the efficiency with which soil produces dust for a given meteorological forcing.

S is dimensionless factor appearing in formulation of dust mobilization mass flux $F_{d,j}$ [kg m^{-2} s^{-1}] (e.g., Zender et al., 2003a):

$$F_{d,j} = TA_m S\alpha Q_s \sum_{i=1}^{I} M_{i,j} \qquad (1)$$

where T is a globally uniform tuning factor, A_m is bare soil fraction, α is saltation-sandblasting mass efficiency (Alfaro et al., 1997), Q_s is horizontal saltation mass flux, and $M_{i,j}$ is the mass fraction of each source mode i carried in each transport bin j. Visit `http://dust.ess.uci.edu/dead` for more details.

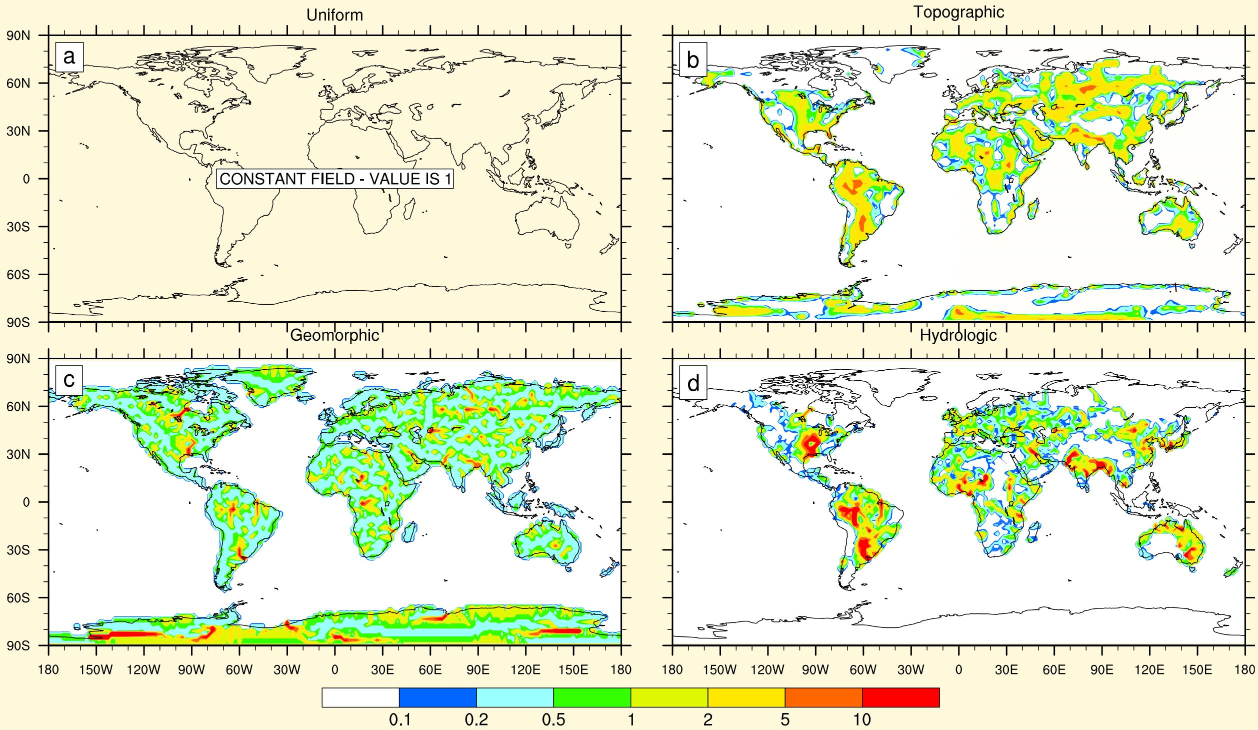
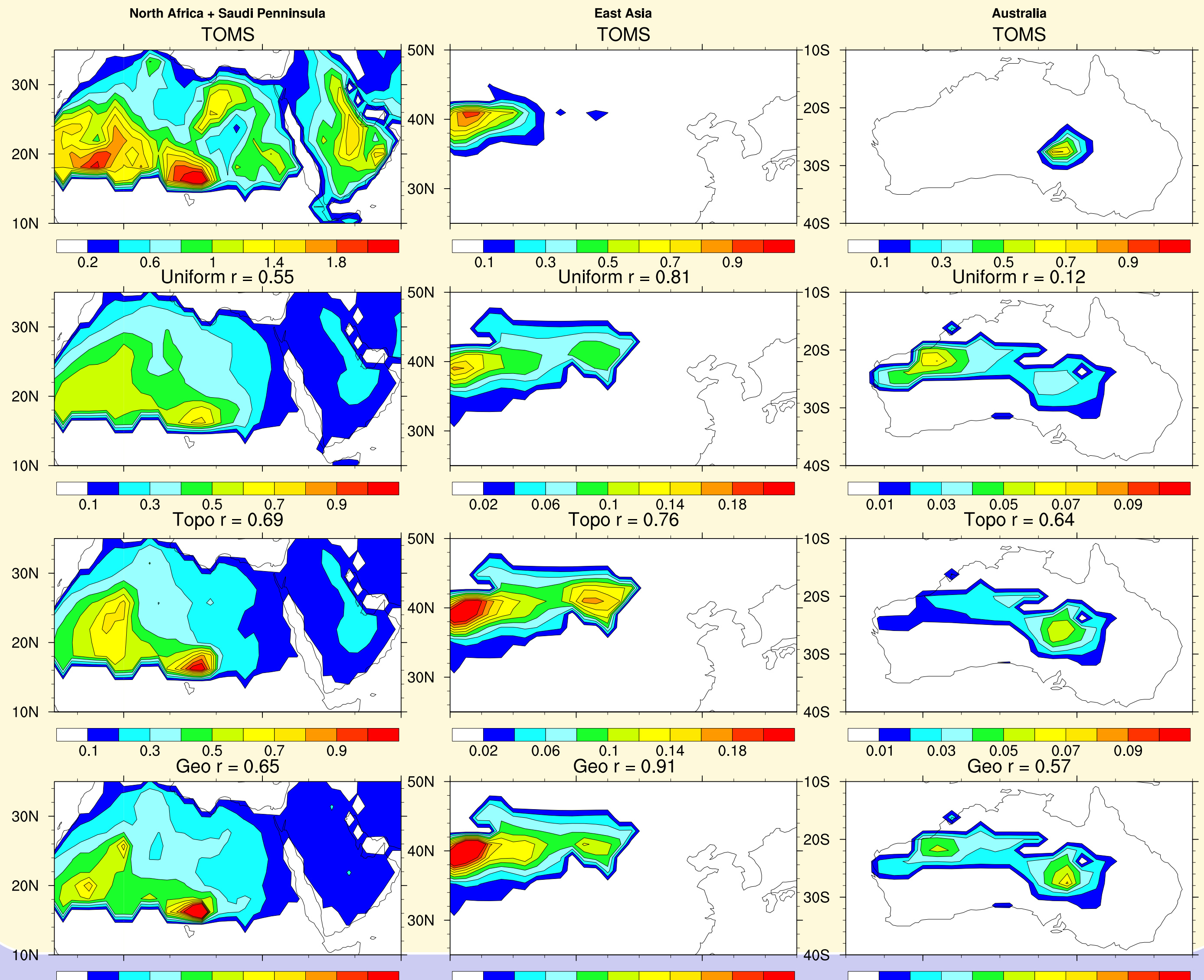


Figure 1: Soil spatial erodibility constraints S for four hypotheses: (a) Uniform, (b) Topographic, (c) Geomorphic, (d) Hydrologic (Zender et al., 2003b).



North Africa + Saudi Penninsula
East Asia
Australia
TOMS
Uniform r = 0.55
Uniform r = 0.81
Uniform r = 0.12
Topo r = 0.69
Topo r = 0.76
Topo r = 0.64
Geo r = 0.65
Geo r = 0.91
Geo r = 0.57
10N
20N
30N
40N
50N
10S
20S
30S
40S
0.2 0.6 1 1.4 1.8
0.1 0.3 0.5 0.7 0.9
0.02 0.06 0.1 0.14 0.18
0.01 0.03 0.05 0.07 0.09

2. Temporal Erodibility Constraints

Motivation:

- Supply-limited regions documented on local, regional scales (Gillette et al., 2001; McTainsh et al., 2002; Okin and Reheis, 2002).
- Important on global scales?
- Remediate underprediction of seasonal to interannual dust variability, e.g., Mahowald et al. (2003)?

Strategy:
Time series analysis of relation between satellite-retrieved mineral dust aerosol anomalies and antecedent climate anomalies in Earth's dustiest regions.

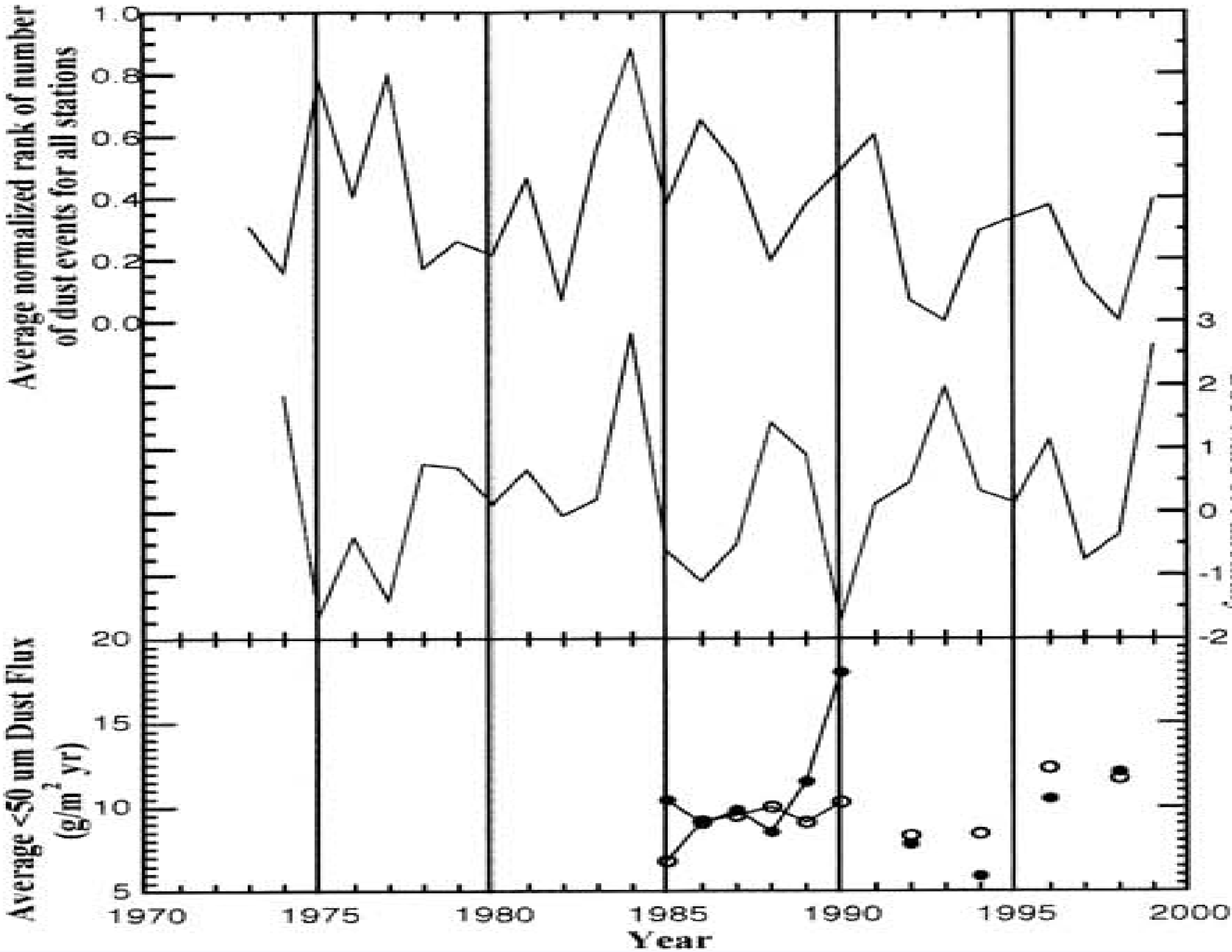


Figure 3: Dust storm frequency (and dust flux) are anti-correlated with previous year's DJF Niño 3.4 anomaly (and precipitation) *except* 1984 and 1999, which followed strongest ENSOs. (Okin and Reheis, 2002).

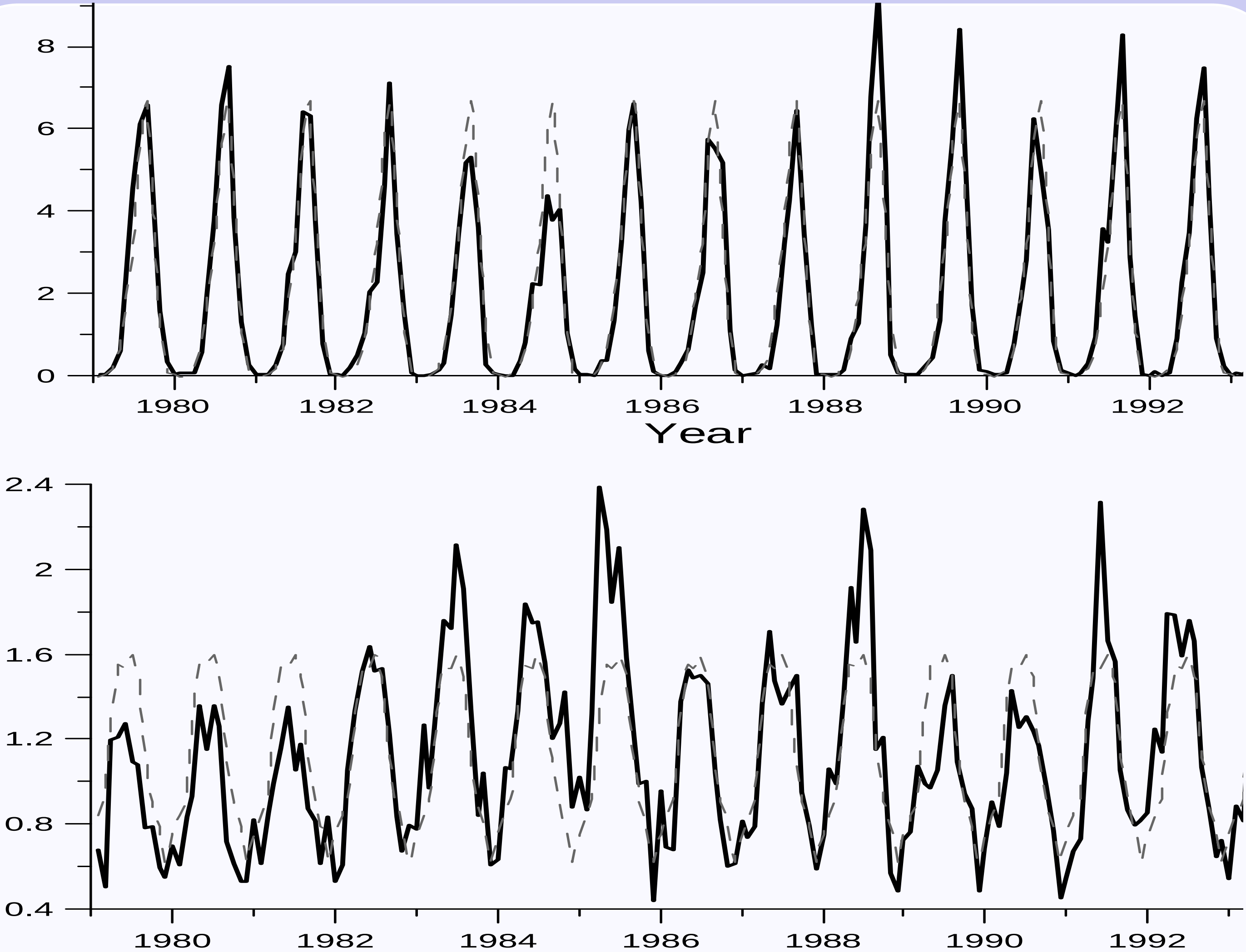


Figure 4: Monthly mean satellite-derived (a) GPCP precipitation [mm d^{-1}] and (b) TOMS dust Aerosol Optical Depth in Eastern Sahel from 1/79–4/93.

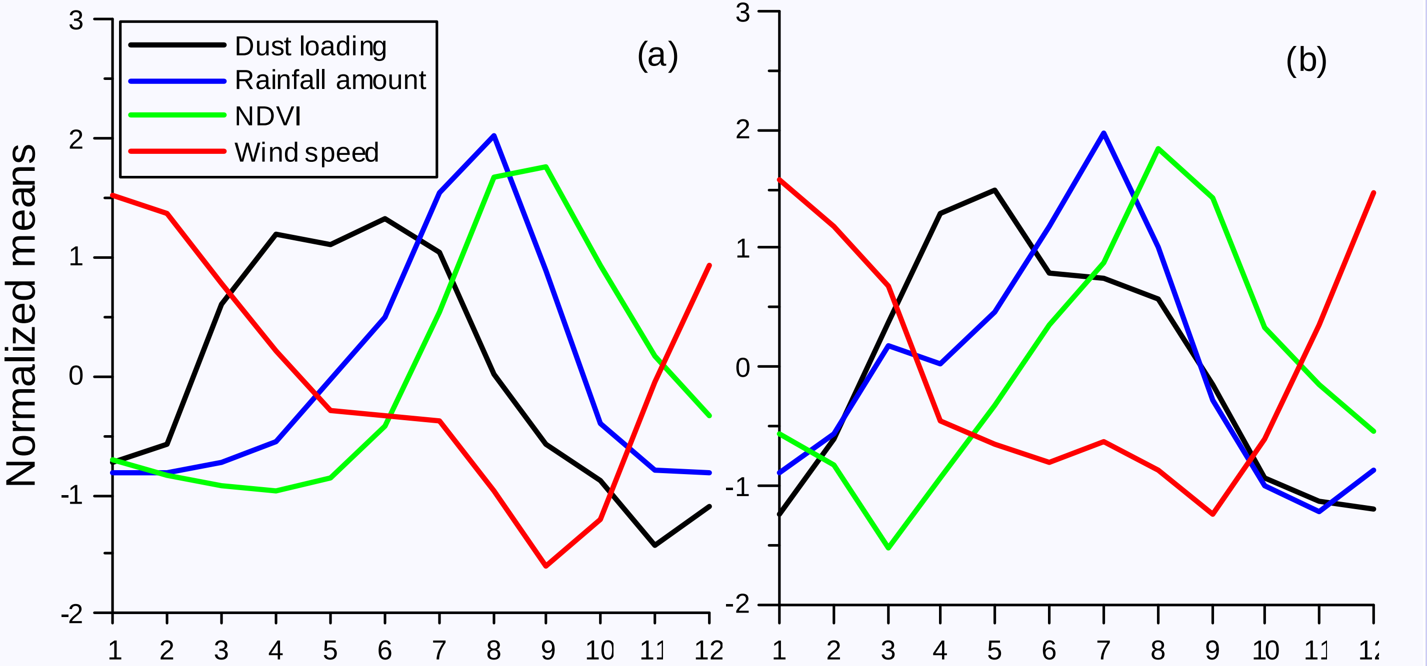


Figure 5: Normalized seasonal cycle of atmospheric dust (black), precipitation (blue), NDVI (green), and surface wind speed (red) over (a) Eastern Sahel, (b) Tarim Basin (Zender and Kwon, 2005).

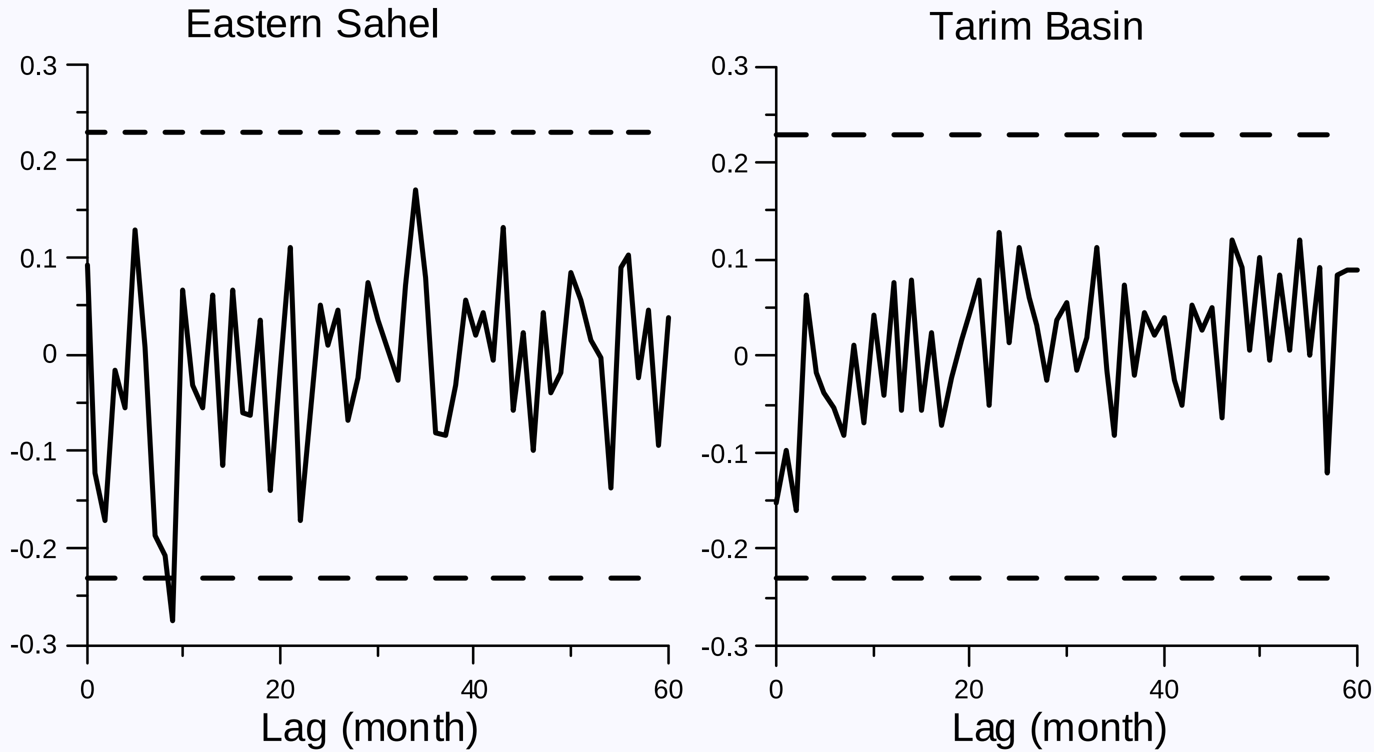


Figure 6: Cross-correlation of monthly mean seasonal precipitation and dust AOD anomalies over the (a) Eastern Sahel and (b) Tarim Basin. Dashed lines at ± 0.23 show $p = 0.01$ confidence levels.

Table 1: **Erodibility Responses of Major Dust Source Regions**[a]

Region	P, τ	P, N	N, τ	P, U	U, τ	Cat.[b]
Eastern Sahel	$-0.27(9)$	$+0.33(1)$	$-0.31(0)$			I
Bodélé Depression	$-0.28(9)$	$+0.26(9)$	$-0.31(0)$			I
Western US	$-0.22(0)$	$+0.47(1)$	$-0.35(0)$			I
Lake Eyre Basin	$-0.36(1)$	$+0.61(1)$	$-0.29(1)$			I
Botswana	$-0.39(1)$, $-0.23(0)$	$+0.56(2)$, $+0.31(0)$	$-0.28(9)$			I
Gobi Desert			$-0.28(2)$			I
China Loess Plateau	$-0.27(0)$					II
Great Salt Lake	$-0.37(0)$	$-0.27(0)$		$+0.26(0)$		II
Zone of Chotts	$+0.21(44)$	$+0.42(26)$		$+0.26(0)$		III
Tigris/Euphrates	$+0.21(14)$	$-0.26(8)$				III
Saudi Arabia	$+0.36(0)$	$-0.27(0)$				IV
Oman	$+0.40(0)$					IV
Tarim Basin			$+0.28(21)$		$+0.23(0)$, $-0.24(2)$	IV
Thar Desert	$+0.25(0)$, $-0.24(1)$, $-0.21(2)$	$+0.57(1)$	$-0.3(0)$, $-0.33(10)$	$-0.35(0)$	$+0.3(1)$	I, IV

[a]Highly significant ($p < 0.01$) cross-correlations r between autoregression-corrected erodibility indicators (dust AOD τ) and climate constraints (precipitation P, NDVI N, and wind speed U) from 1979–1994. Lag in months of indicated cross-correlation is shown in parentheses.

[b]Erodibility Category Assigned

Table 2: **Erodibility Categories of Major Dust Source Regions**

Cat.	Response[a]	Regions
I	$P \downarrow \tau, P \uparrow N, N \downarrow \tau$ Strong moisture and vegetation constraints, multiple timescales	Eastern Sahel, Bodélé Depression, Western US, Lake Eyre, Botswana, Thar Desert (Gobi Desert)
II	$P \downarrow \tau$ Strong moisture constraints, immediate response	China Loess Plateau, Great Salt Lake
III	$P \uparrow \tau$ Supply-limited, interannual alluvial recharge?	Zone of Chotts, Tigris/Euphrates
IV	$P \uparrow \tau$ Supply-limited, crustal (de-)formation	Saudi Arabia, Oman, Tarim Basin, Thar Desert

[a]Positive and negative correlations indicated by ↑ and ↓, respectively

3. Implications of Supply-Limited Environments

- Supply-limited regions are real (Gillette et al., 2001; McTainsh et al., 2002; Okin and Reheis, 2002) and more prevalent than previously thought (Zender and Kwon, 2005).
- Global dust models assume inexhaustible sedimentary material
- Implement supply-limited constraints as temporal erodibility factor?

$$S_{\text{temporal}} = S_{\text{sediment}} \times S_{\text{crusting}} \tag{2}$$

- Modeling supply limitation may help remediate underprediction of seasonal to interannual dust variability, e.g., Mahowald et al. (2003):

Table 1. Correlation Between Interannual Variability in Model and Observations[a]

	Monthly Correlation	Monthly Anomaly Correlation	Annual Correlation	Number of Months of Data	Daily Averaged Correlation
Barbados	**0.66 (0.77)**	**0.46 (0.52)**	**0.38 (0.45)**	260	0.51 (0.63)
Izana	**0.64 (0.74)**	**0.51 (0.55)**	**0.64** (0.63)	104	0.31 (0.60)
Bermuda	**0.83 (0.86)**	**0.74 (0.47)**	**0.84** (0.62)	108	0.49 (0.61)
Miami	**0.72 (0.62)**	**0.39 (0.23)**	0.03 (−0.12)	227	0.65 (0.51)
Midway	**0.64 (0.76)**	**0.27** (0.18)	**−0.41** (−0.35)	109	0.84[b] (0.57)
Hawaii	**0.74 (0.86)**	**0.38 (0.47)**	**0.48** (0.27)	62	0.46[b] (0.77)
Enewtak	**0.40 (0.63)**	−0.00 (0.18)	**0.71** (0.70)	43	0.81[b] (0.82)
Funafuti	−0.08 (0.01)	−0.02 (0.03)	NAN (0.20)	40	
Mace Head	**0.34 (0.49)**	**0.27 (0.27)**	**−0.53** (−0.60)	59	
Norfolk	0.09 (0.23)	0.30 (0.14)	0.39 (0.09)	44	

4. Conclusions

- Earth's dustiest regions fall into four distinct erodibility classes which include both positive and negative dust-emission responses to precipitation anomalies
- Supply-limited erodibility more widespread than previously thought, and include short and long timescales consistent with soil crust disruption and alluvial replenishment, respectively
- Precipitation-induced vegetation anomalies alter erodibility constraints on monthly, and possibly shorter, timescales, in many important regions (Tarim, Saudi Arabia, Oman)
- Sediment constraints may cause regions which respond similarly to mean climate to respond differently to climate anomalies

5. References

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