Sensitivity of the climate system to the magnitude of dust emissions and nonlinear responses in CESM

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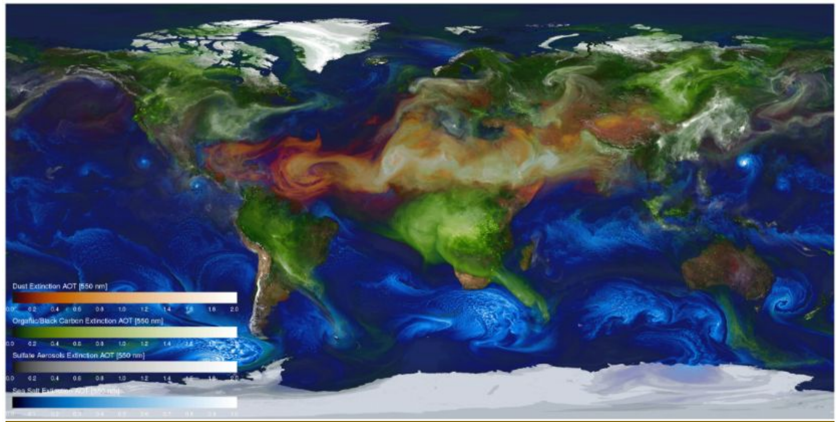
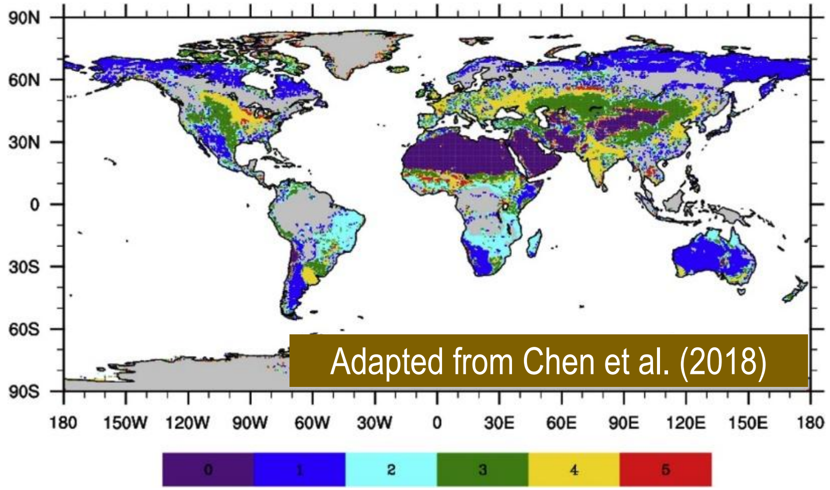
❑ (Mineral) DUST?



Adapted from Castellanos et al. (2019, p.4, Figure 2)

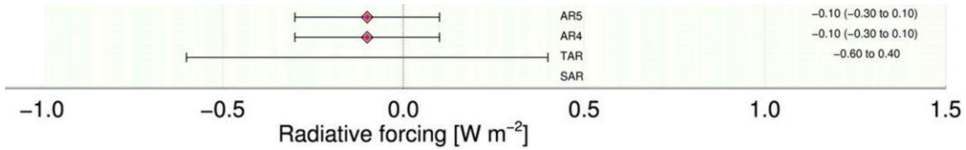


Adapted from Chen et al. (2018)

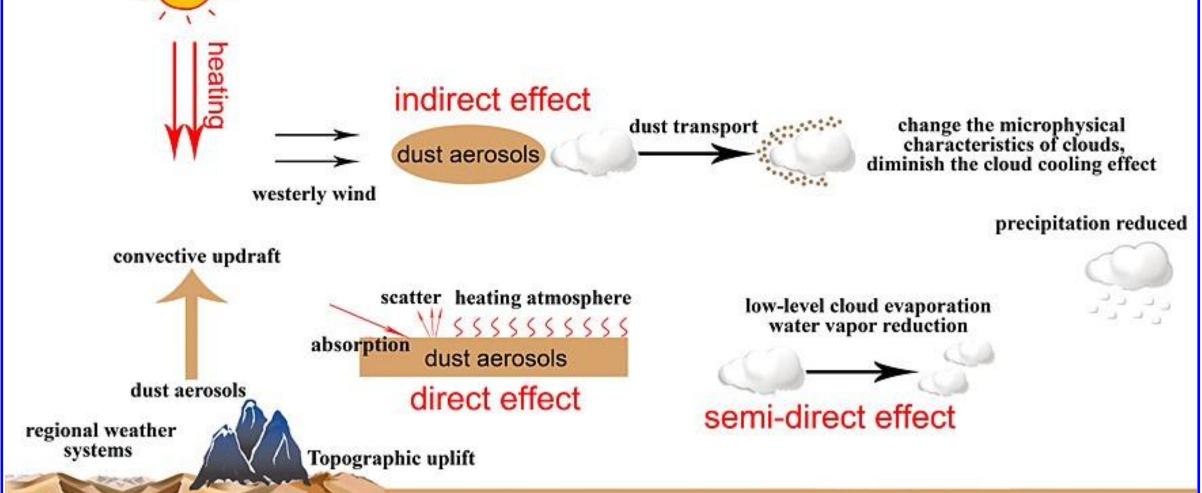
0-2: natural sources
0: deserts
1: Savannahs
2: shrublands

3-5: anthropogenic
3: grasslands
4: croplands
5: crop mosaics

- **Asymmetric** spatial distribution, mainly low-latitudes in NH
- Occurrence and frequency are **highly season-dependent**
- **Large uncertainty** in long-term changes
  - Dust-radiation interactions in the IPCC Assessments



<Dust effects on climate>



Adapted from Huang et al. (2014, p.13, their Figure 8)

We aim

- **To assess the climate sensitivity to the magnitude of dust emissions**
- **To investigate dust impacts on ENSO characteristics**
- **To measure the linearity of dust impacts on climate**

using present-day simulations.

❖ Present-day simulations using **CESM 1.2.2**

- Components of model:

  CAM5 for ATM, **CLM4** for LAND, **POP2** for OCEAN, **CICE** for SEA-ICE

- Using the **MAM3** scheme for dust aerosols:

  *an **accumulation mode*** between particle diameters of ***0.1-1μm***,

  *a **coarse mode*** between particle diameters of ***1-10μm***

- Model Physics: a default setting for a present-day run from CESM svn repository

- Initial data: a dump file from an earlier long run of CESM for the present-day starting from the year 2000

- Horizontal resolutions: 1.9°x2.5° for ATM and LAND, 1° for OCEAN and SEA-ICE

- **Dust** parameterisation: originated from the DEAD model

Dust parameterisation in CESM 1.2.2

- Based on the dust emission scheme by Zender et al. (2003)

$$F_{d,j} = T\, A_m\, S\, \alpha\, Q_s \sum_{i=1}^{I} M_{i,j}$$

$F_{d,j}$: total vertical mass flux of dust

T : a global tunning factor

A_m: emission constraints by vegetation and by snow

S : a source erodibility factor

α : the sandblasting mass efficiency

Q_s: vertical mass flux of dust (a function of wind friction velocity)

I = 3 source modes

$M_{i,j}$: mass fraction of each source mode *i* in each dust bin j

The entrainment of dust is a function of …

- **wind friction velocity**
- **leaf area index**
- **soil moisture**
- snow cover
- soil erodibility

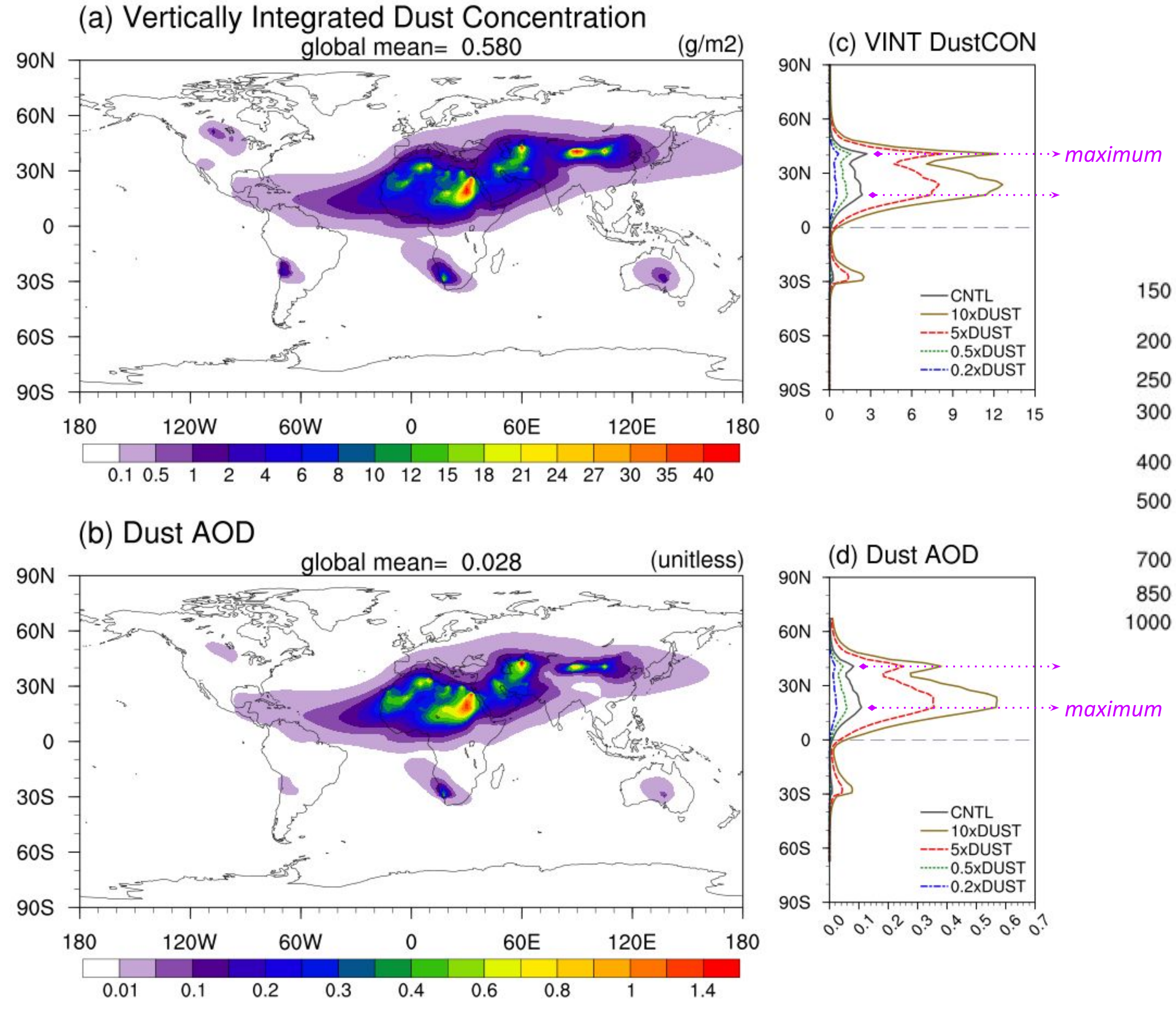
Experimental design for sensitivity

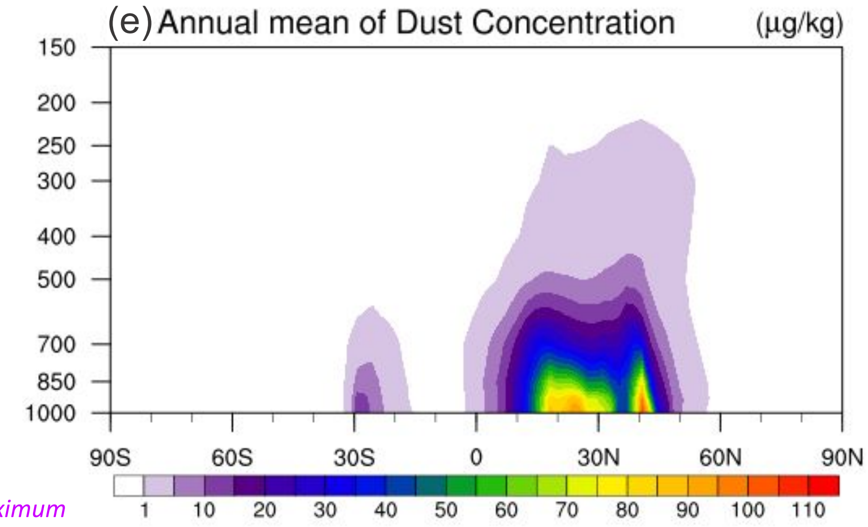
Suite	Experiments	SST	Running period	Purpose
A (coupled)	**1xDUST (CNTL)**	Interactively coupled ocean model	250 years including spin-up, and analysed the last 200 years	To quantify climate responses to changes in dust emissions
	10xDUST			
	5xDUST			
	0.5xDUST			
	0.2xDUST			
B (atmospheric only)	fSST_CNTL	Prescribed climatologic SST from CNTL (the last 30-year)	50 years including spin-up, and analysed the last 30 years	To estimate the ERF and the fast precipitation response
	fSST_5xDUST			
	fSST_0.2xDUST			

- For increments of dust emissions, none of the factors for dust emissions are modified.
- Modifying the equation of total vertical mass flux of dust by 0.2x, 0.5x, 5x, and 10x in each mode
- The two-sample Kolmogorov-Smirnov test applied

*** GHGs: fixed values from the year 2000**

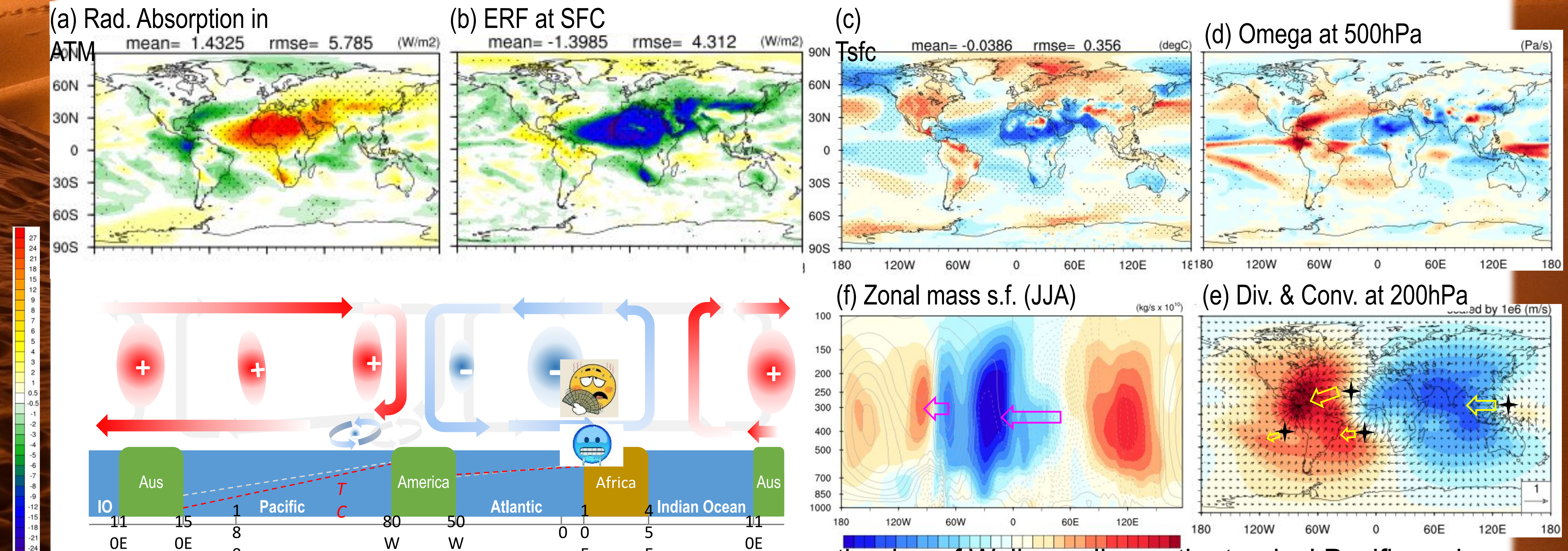
Dust distributions in the control experiment





❑ Increased dust case (5xDUST)

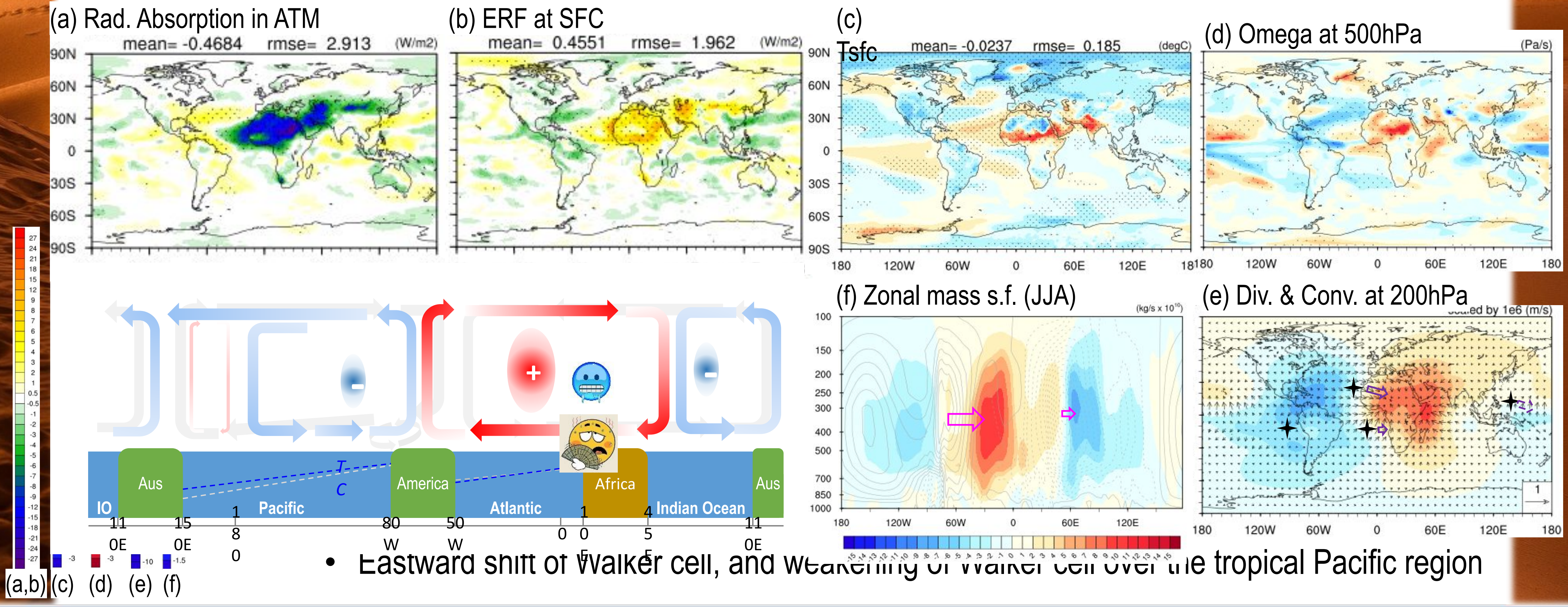
- Abundant dust particles in the atmosphere cause atmospheric warming but surface cooling
- Strong atmospheric warming, anomalous ascending movement
- The anomalous divergence over Asia and Africa, and convergence over Central America at 200hPa



- Westward shift of Walker cell, and strengthening of Walker cell over the tropical Pacific region

❑ Reduced dust case (0.2xDUST)

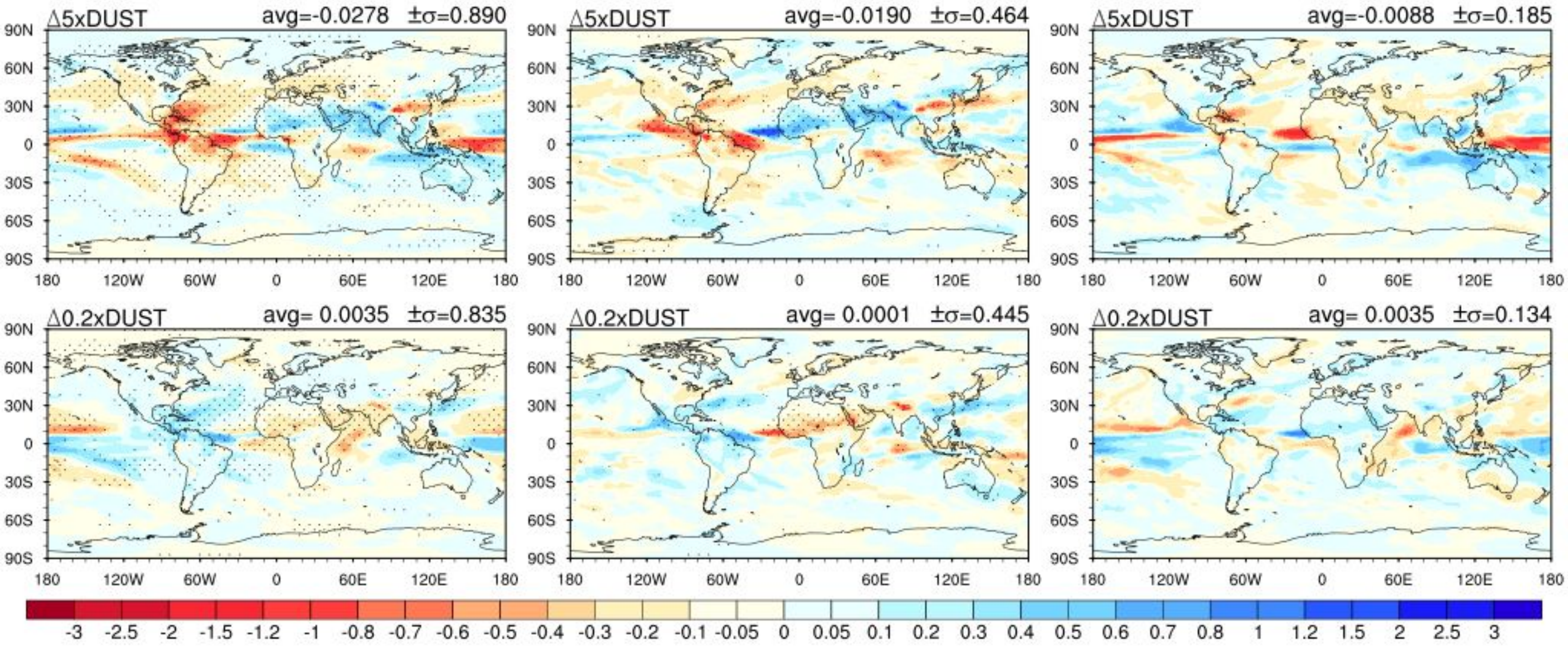
- Fewer dust particles in the atmosphere cause atmospheric cooling but surface warming
- Strong atmospheric cooling, anomalous descending movement over the Sahel and tropical Atlantic
- The anomalous convergence over Africa, and divergence over Central America at 200hPa



- Eastward shift of Walker cell, and weakening of Walker cell over the tropical Pacific region

❑ Response of the hydrological cycle to dust forcing

(a) Total precipitation (b) Fast responses (c) Slow responses

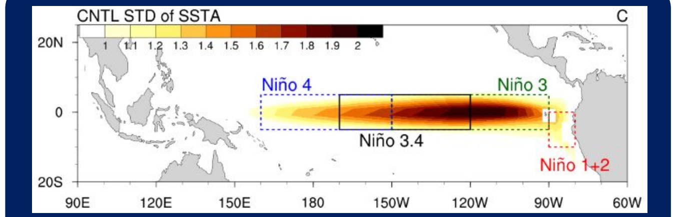


$$\Delta P_{tot} = \Delta P_{fast} + \Delta P_{slow}$$

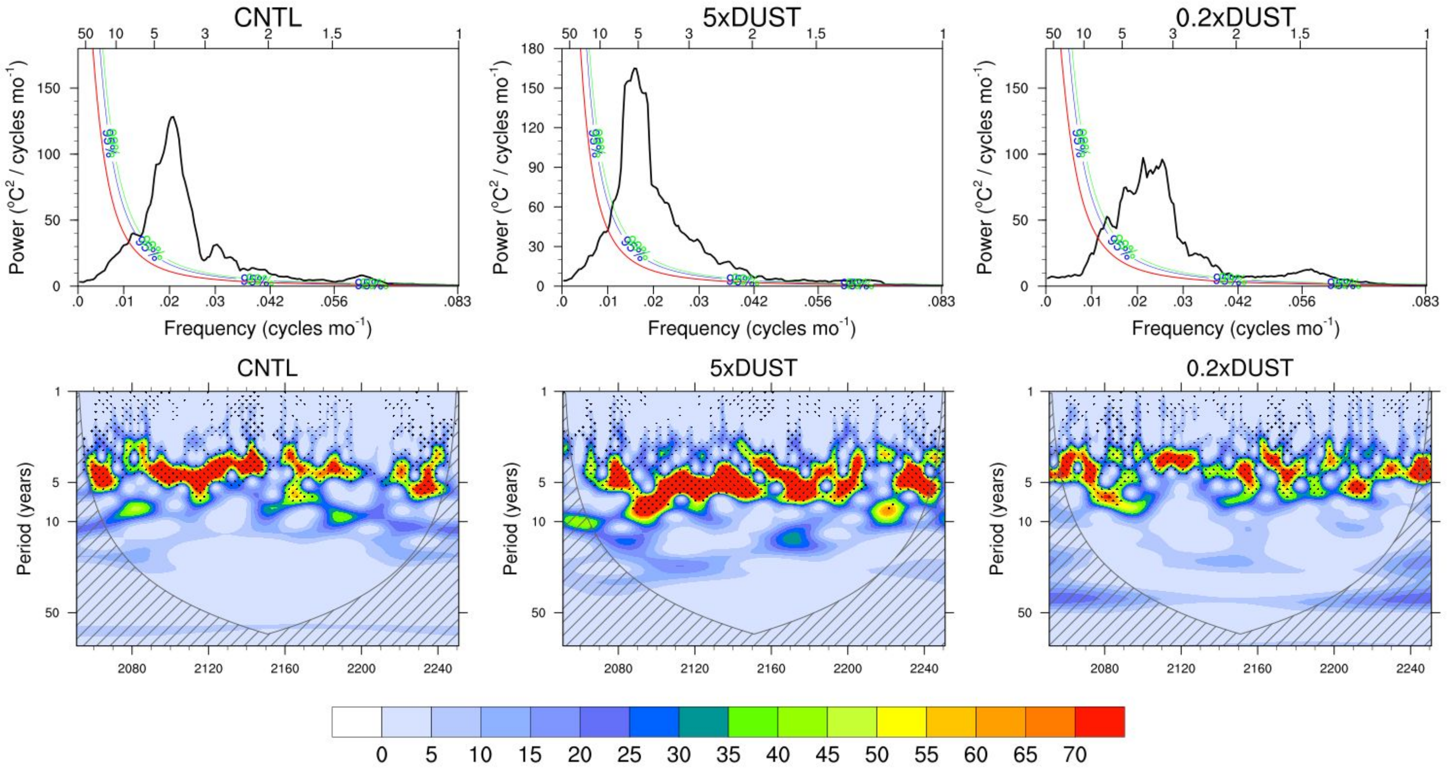
$$\Delta P_{fast} = \Delta P_{fSST}$$

❑ Changes in ENSO characteristics

	La Niña			El Niño		
	CNTL	5xDUST	0.2xDUST	CNTL	5xDUST	0.2xDUST
Number of month	764	835	753	688	641	738
Event frequency	47	41	51	44	37	50
Avg. period of event	16.25	20.4 (25.5%)	14.8 (-9%)	15.6	17.3 (10.9%)	14.8 (-5.1%)



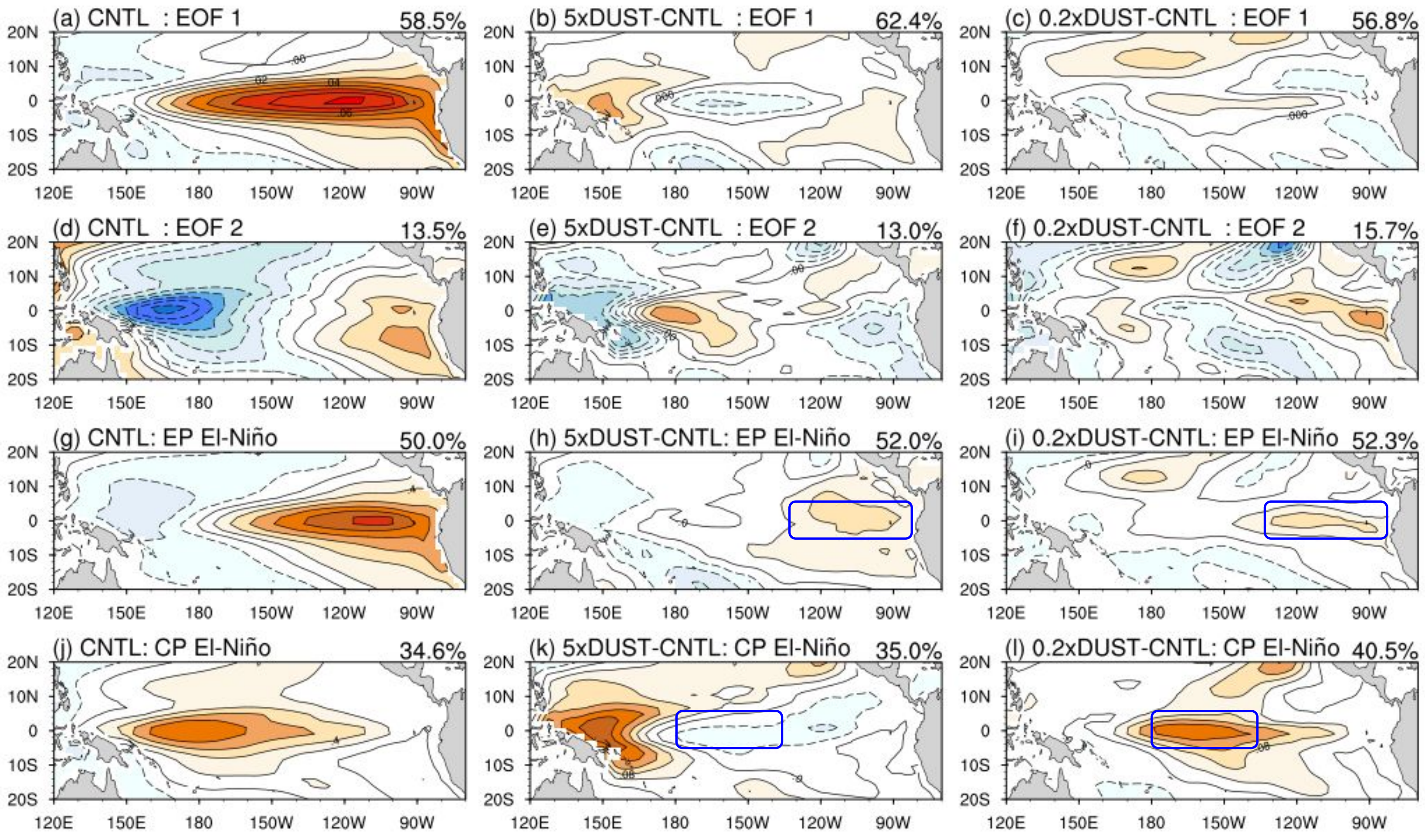
Definition of ENSO from NOAA CPC:
-0.5°C < Niño 3.4 SSTA < +0.5°C
→ a 3-month running mean



Compared to CNTL	5xDUST	0.2xDUST
Period (frequency)	Prolonged (lower)	Shorter (higher)
Power of a signal (periodic signal)	stronger	weaker
Concentrated power during time-series	more dense	less dense

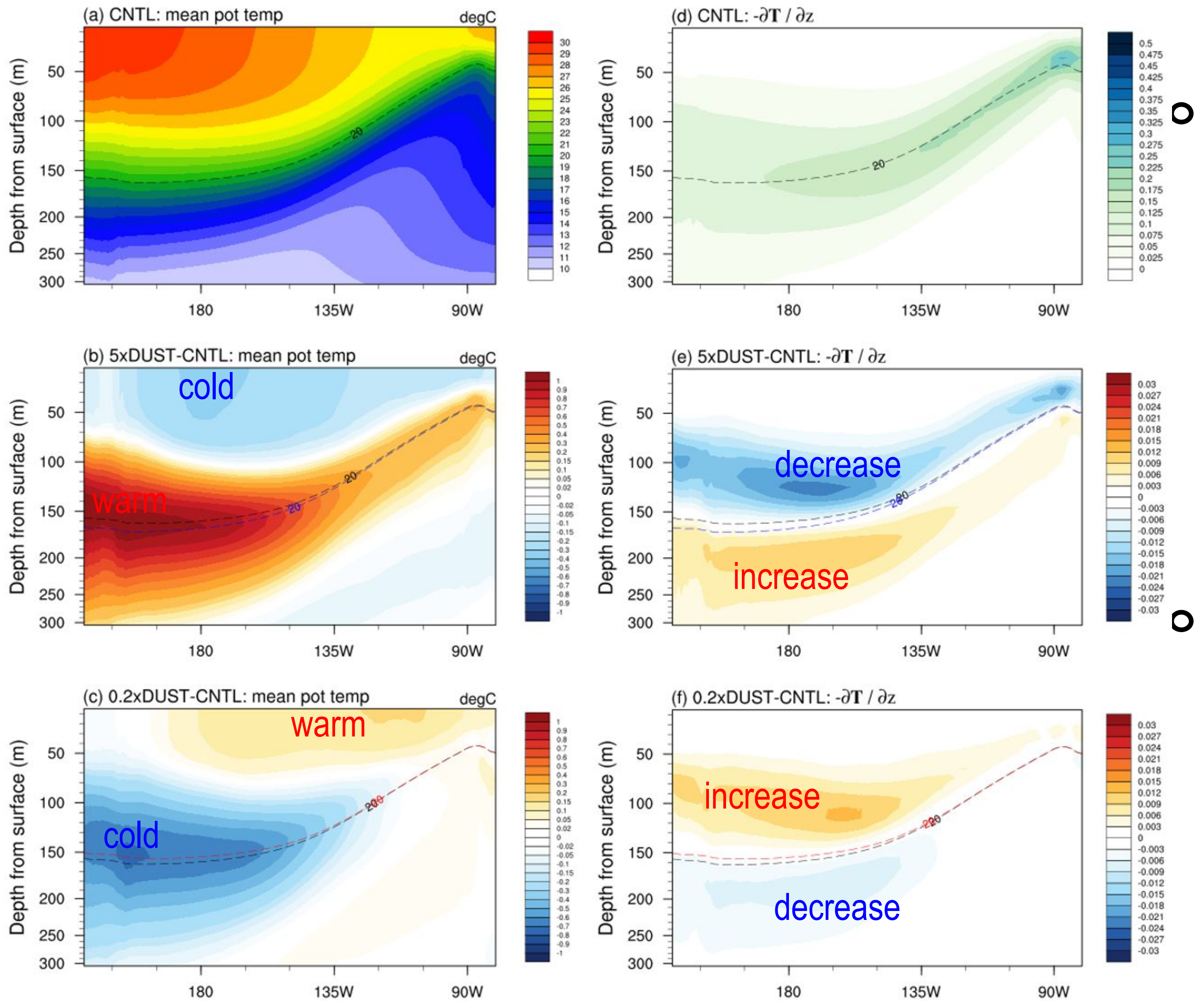
❑ Changes in ENSO diversity

- ENSO diversity: using a combined linear regression-EOF analysis *introduced by Kao and Yu (2009)*



II. Can dust aerosols modulate ENSO?

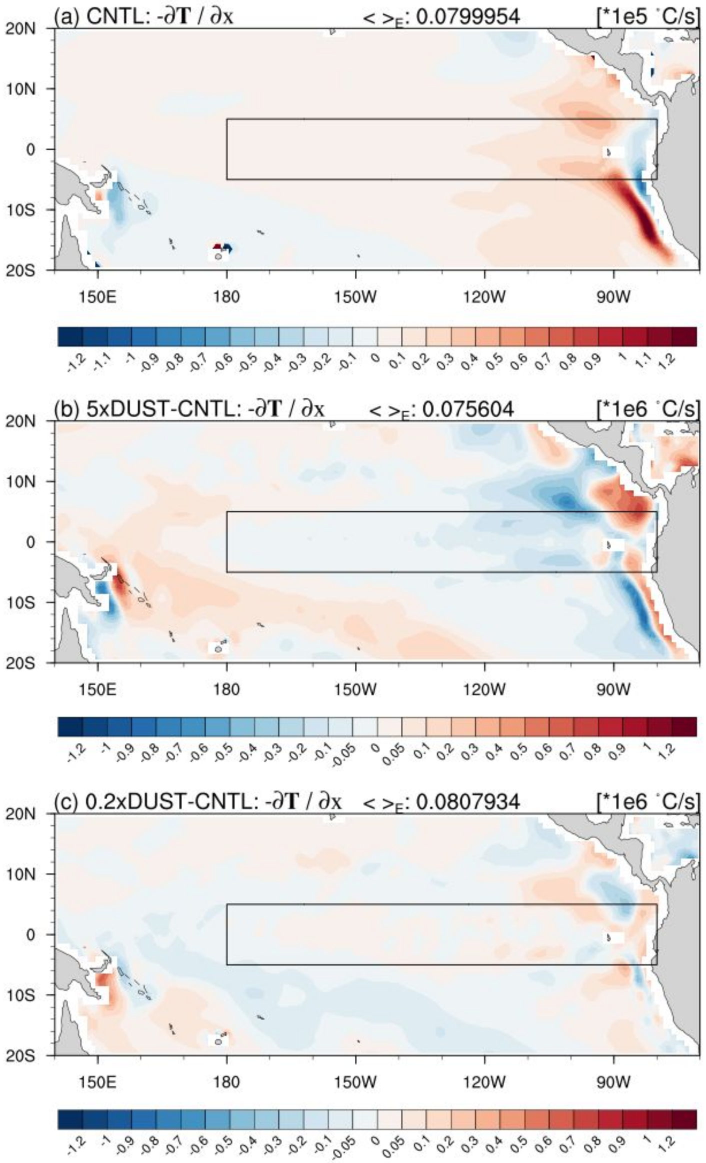
Subsurface temp profiles   Ocean thermal stratification



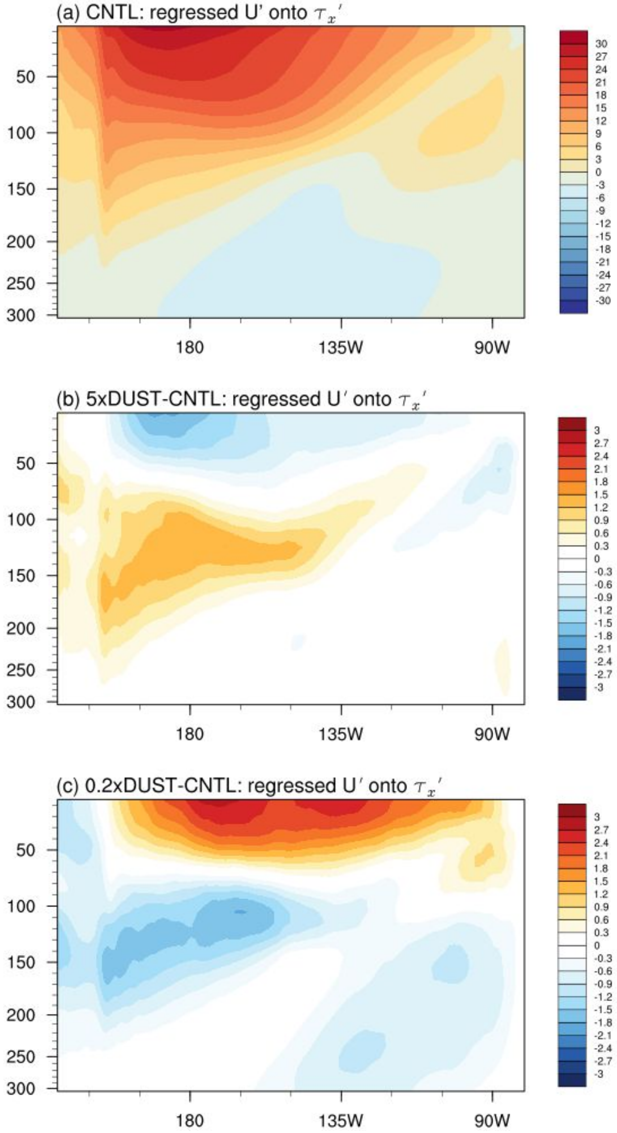
- **5xDUST**
  - Weakened oceanic stratification
  - Z20 is deeper, especially in the western Pacific
- **0.2xDUST**
  - Intensified oceanic stratification
  - Z20 is shallow

II. Can dust aerosols modulate ENSO?

Zonal advection

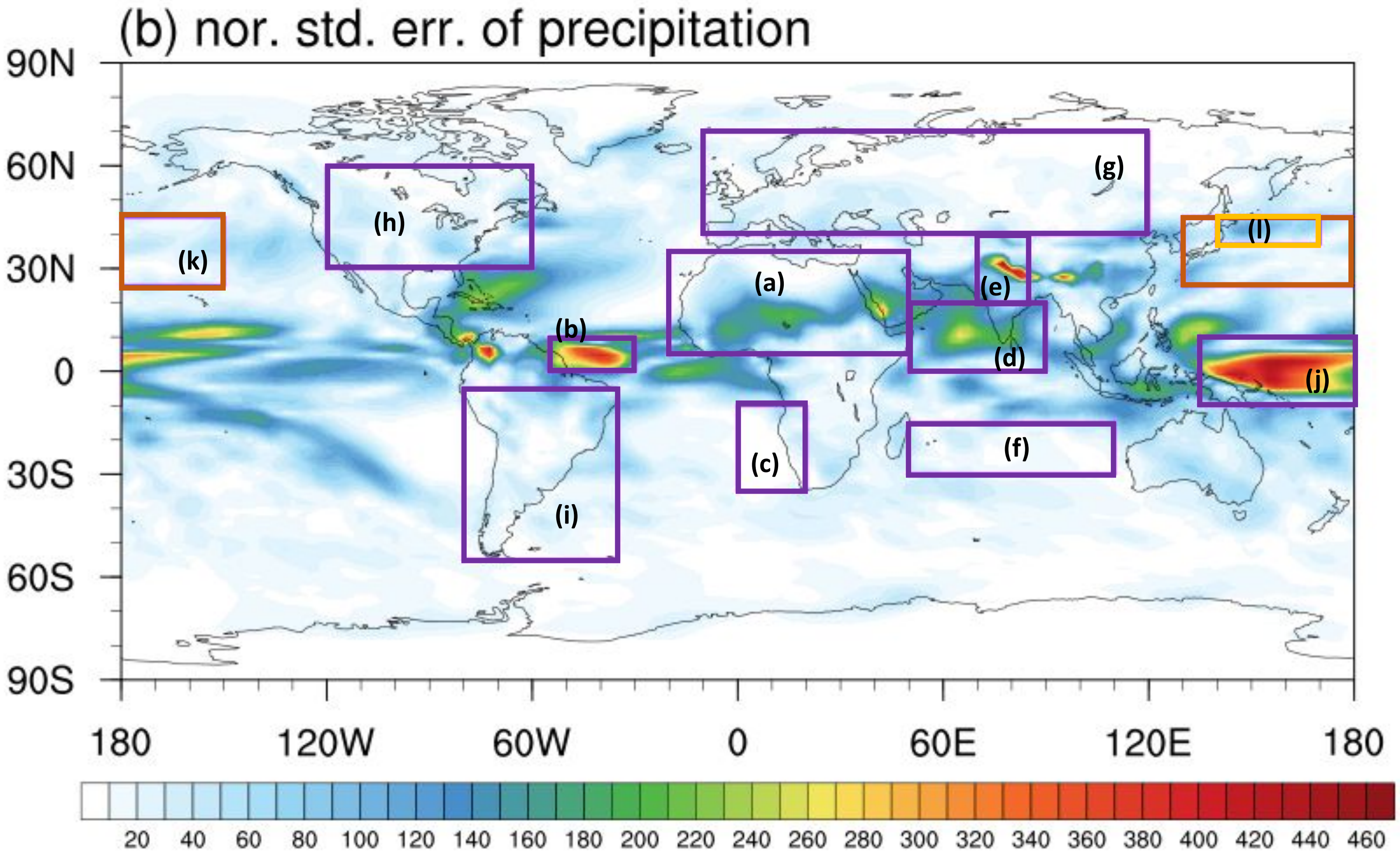


Upper layer responses
(zonal current response)



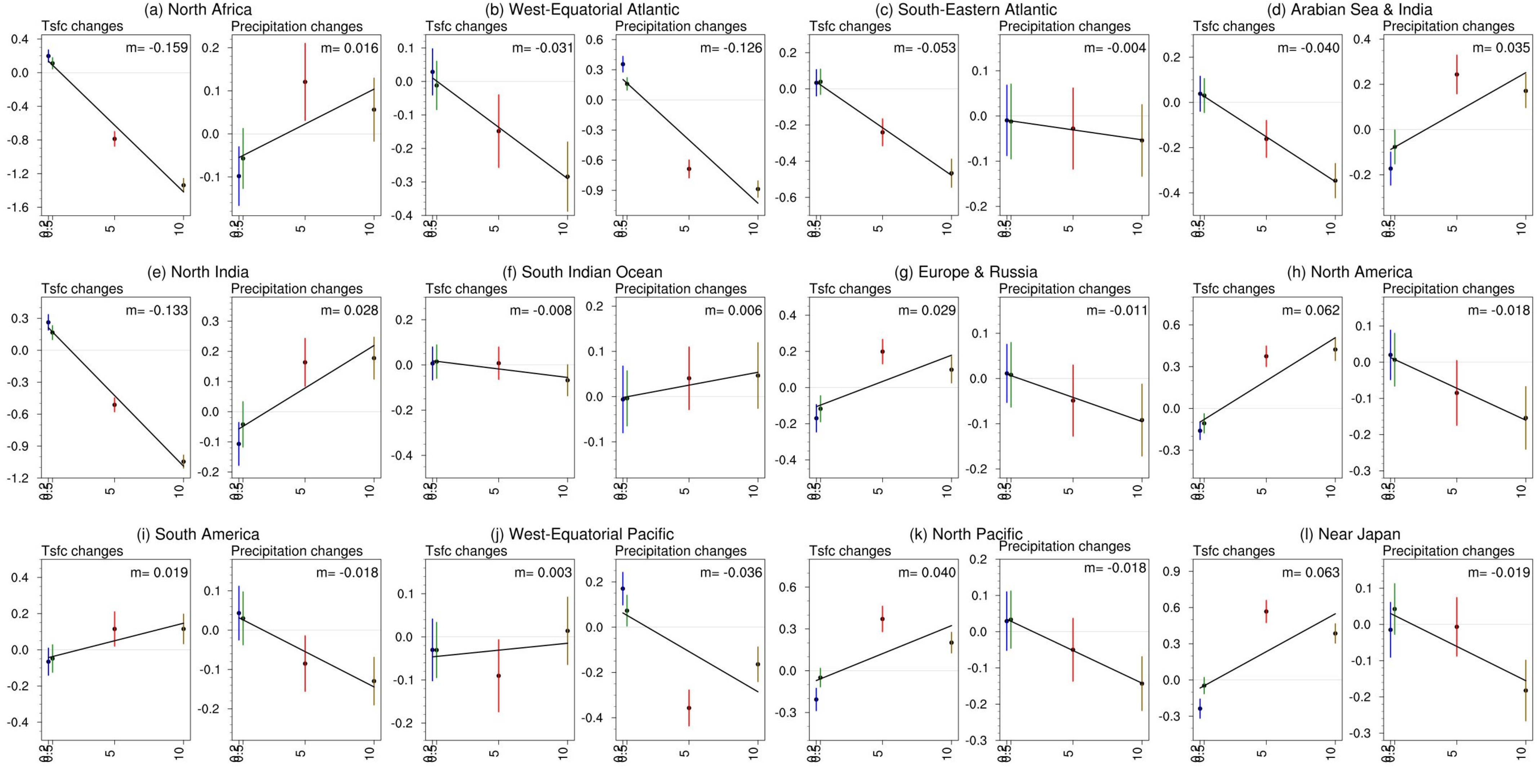
- **5xDUST**
  - Weakened zonal advection and zonal current response
- **0.2xDUST**
  - Stronger zonal advection and zonal current response in the mixed layer

❑ Does dust affect climate linearly?



(a) North Africa
(b) West Equatorial Atlantic
(c) South-eastern Atlantic
(d) Arabian Sea + India
(e) North India
(f) South Indian Ocean
(g) Europe + Russia
(h) North America
(i) South America
(j) West Equatorial Pacific
(k) North Pacific
(l) Near Japan

❑ Does dust affect climate linearly?



SUMMARY

- Dust source regions underwent substantial radiative heating/cooling in the lower atmosphere
   modulating the climatological subsidence of regions
   consequently leading to a shift of the Walker circulation also its intensity

- The magnitude of global dust emissions can alter ENSO characteristics and diversity

  - Increased dust: contributing to a more prolonged duration and dense power
    weak zonal advection, and weakened stratification
    favourable to occur classical Eastern Pacific-type ENSO

  - Reduced dust: contributing to shorter duration and less power
    relatively strong zonal advection, and intensified stratification
    favourable for the occurrence of Central Pacific-type ENSO

- Global mean changes due to the magnitude of global dust emissions respond linearly,
  BUT nonlinear responses were also shown on the regional scale