Quantifying Dust Emission and Deposition in Western Saudi Arabia and Red Sea Using Micro-Scale Land-Surface Model and High Resolution Surface Data

Weichun Tao[1], Georgiy L Stenchikov[1], Stoitchko D. Kalenderski[1], HamzaKunhu Bangalath[1], Zongliang Yang[2], Mingjie Shi[2]

[1]King Abdullah University of Science and Technology, Thuwal, Saudi Arabia

[2] Department of Geological Sciences, Jackson School of Geosciences, The University of Texas at Austin, Austin, TX, USA

جامعة الملك عبدالله
للعلوم والتقنية
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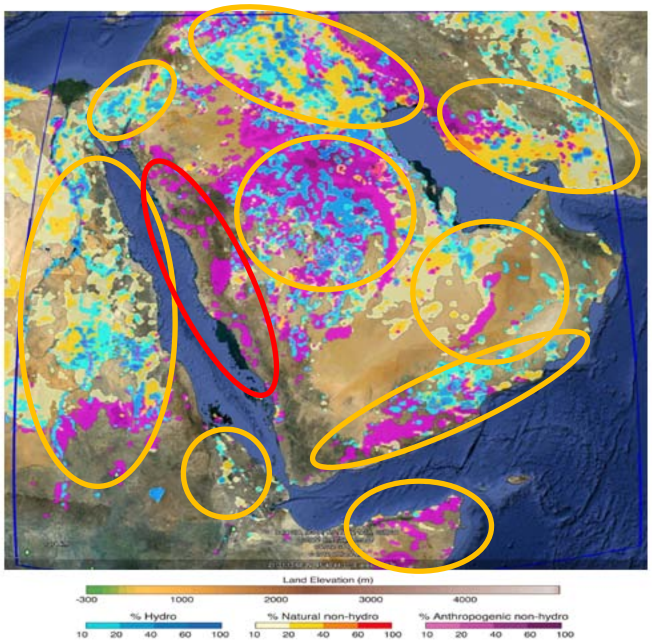
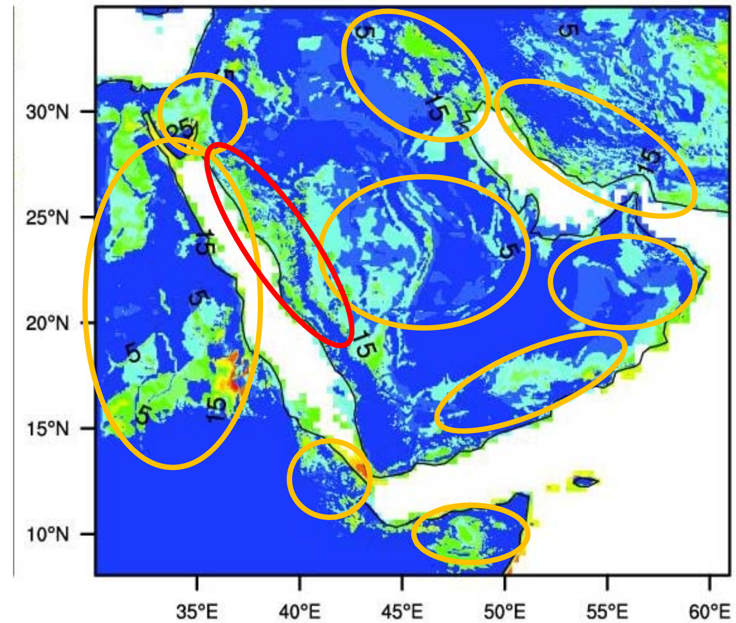
Introduction

- The characteristics of dust emission in red sea coastal area
- Dust is an important nutrient supply for the Red Sea
- Arabian coast of the Red Sea is a hot spot of dust generation
- Dust could be generated by breezes and by synoptic circulation
- The source area is quite narrow therefore high spatial resolution model and data input are required

Hot Spots in Arabia





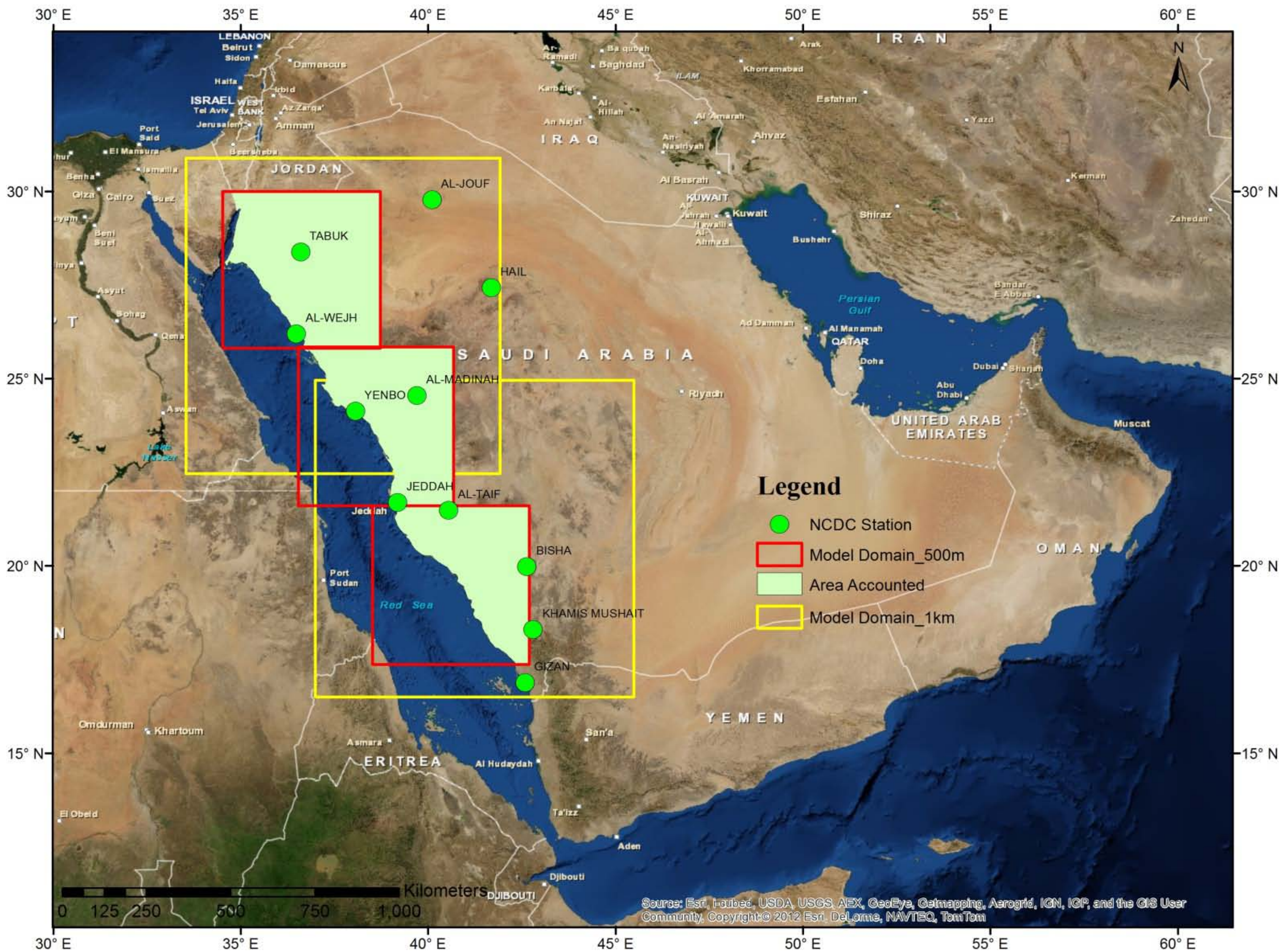
Dust source spatial distribution in Arabia
(Yellow and red circle: source location)
Left: Ginoux et al., 2012; Right: model result

Science Questions:

- How high model resolution we need to capture the microscale processes?
- What is the impacts of data resolution and land parameter changes on the simulated processes?
- How to improve dust source erodibility parameterization?
- How much dust is emitted and deposited to the Red Sea?
- What is dust composition?

Domain

Land Domain Shading Areas: 452,099 km^2



Model Set Up

- Offline Community Land Model Version 4
- Atmospheric forcing : output from 10 km-resolution WRF model for 2009

CASES	Objective	Resolution	Land Parameters	Original Resolution of data
0	Control	500m x 500m	CLM4 Land	0.5° x 0.5°
1	Resolution sensitivity	1km x 1km 5km x 5km 25km x 25km	CLM4 Land	0.5° x 0.5°
2	Parameter Sensitivity	500m x 500m	MODIS PFT	500m x 500m
			MODIS LAI	1km x 1km
			STATSGO SOIL TEXTURE	1km x 1km
			ERODIBILITY FACTOR	
3	Quantification	500m x 500m	All New Data (MODIS Erodibility)	

Model Validation

- Total flux
  - 10-40 Tg/yr

Region	Particle size	Dust emission (Tg/yr)	Resource	Reference	Convert to this domain (Tg/yr)
Middle East (6,452,972 km²)	0.1-10um	526	CAM	Huneeus et al (2011)	37
		125	GISS		8.8
		348	GOCART		24.4
		531	SPRINTARS		37
		241	MATCH		17
		376	MOZGN		26
Taklimakan Desert	PM10	0.038 kg/m2/yr	US EPA empirical formulas	Jie Xuan et al (2002)	17.2

- Spatial/Temporal Distribution
  - Correlation analysis
    - Correlation of dust emission with reciprocal of NCDC visibility
    - Correlation of dust emission with MODIS DOD
- Dust Event Case-Study

Sensitivity of Total Emission Flux to Model Resolution

	Unit	500m	1km	5km	25km
Winter NDJFMA	Tg/yr	968.23	970.07	978.31	711.79
Summer MJJASO		979.35	979.64	911.10	632.19
Annual		1885.25	1907.86	1618.51	1532.62
Average rate	kg/m2/yr	4.17	4.22	3.58	3.39
Maximum rate	Kg/m2/yr	1140.36	1140.36	1075.81	942.06

- The higher the resolution is, the more dust is emitted because a higher resolution model produces more extremes
- The total flux is most sensitive when the resolution increases from 5km to 1km

Sensitivity of Spatial/Temporal Distribution of Emission Flux to Model Resolution

resolution	R Model vs. reciprocal of visibility	R Model vs. MODIS DOD
500m	0.133	0.0971
1km	0.133	0.0968
5km	0.091	0.0296
25km	0.077	-0.0428

- The results from the higher resolution model compares better with observations than ones from the lower resolution model
- The spatial/temporal distribution of dust emission is most sensitive when resolution increases from 25km to 5km

Sensitivity of Total Emission Flux to Vegetation and Soil Texture

- Increase of vegetation cover decreases dust emission
- Decrease of LAI and SAI increases dust emission
- Decrease of CLAY fraction increases dust emission

Fraction	CLM4	NEW	DIFF
PCT_TREE	1.44	0	-1.44
PCT_SHRUB	0.21	14.57	14.37
PCT_GRASS	3.43	0	-3.43
PCT_CROP	0.02	0.17	0.14
Total vegetation	5.10	14.74	9.64
LAI	0.82	0.05	-0.76
SAI	0.26	0.01	-0.26
PCT_CLAY	17.82	10.63	-7.19

Tg/yr	Control	CASE2_ PFT	CASE2_ LAI	CASE2_ SOIL
Winter NDJFMA	968.23	825.40	1147.29	1003.96
Summer MJJASO	979.35	819.46	1094.45	944.75
Annual	1947.57	1644.86	2241.74	1948.71
DIFF		-302.71	294.17	1.14

Sensitivity of Spatial/Temporal Distribution of Emission Flux to Vegetation and Soil Texture

- Updating LAI data Improves the dust emission simulation
- Correlation of estimated dust emission with DOD is hampered by the dust transport from other areas
  - Statistical methods could help to extract the fraction of local dust DOD from the total one

	R Model vs. reciprocal of visibility	R Model vs. MODIS DOD
CASE2_PFT	0.088	0.078
CASE2_LAI	0.148	0.026
CASE2_SOIL	0.119	0.069
Control	0.133	0.097

Sensitivity of Total Emission Flux to Erodibility factor

- Using erodibility factor reduces the simulated dust emission
- Using topographic erodibility factor reduces dust emission flux insufficiently
- Geomorphic and statistical erodibility factors give more reasonable results

Erodibility Factors		Algorithm	Resolution	Reference
Gnx1	Topographic	Relative elevation in surrounding basins + vegetation mask	0.25° x 0.25°	Ginoux et al 2001
ASTmsk	Topographic	Gnx1+ ASTER DEM +vegetation mask	1′ x 1′	Ginoux et al 2001
AST	Topographic	Gnx1+ ASTER DEM	1′ x 1′	Ginoux et al 2001
Zdr	Geomorphic	Upstream area (not taped in near coast area)	0.23° x 0.31°	Zender et al 2003
MDB	Statistical	Frequency of high DOD occurence	1km x 1km	Ginoux et al 2010, 2012

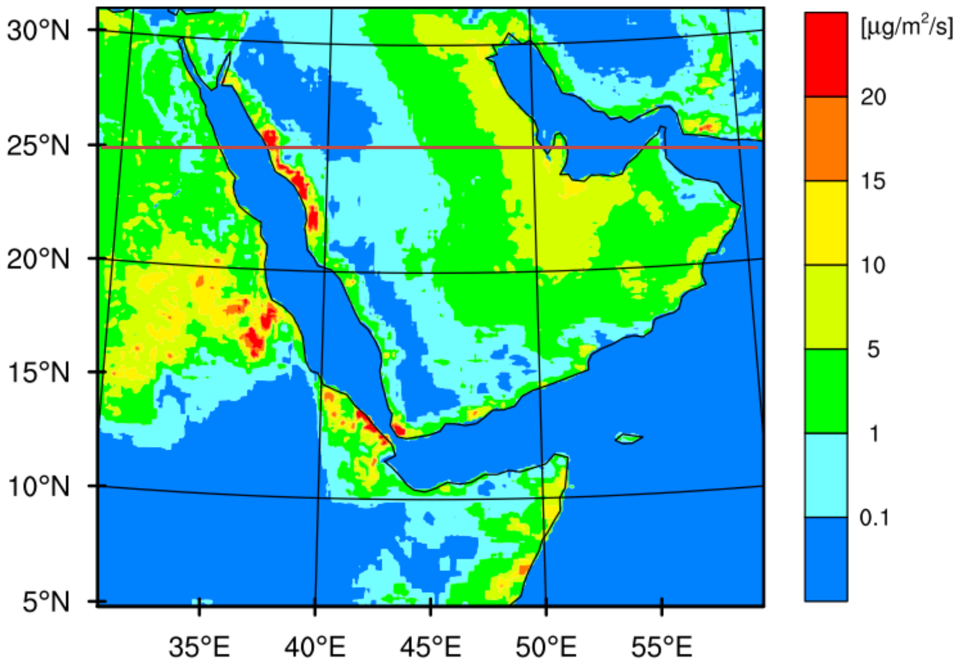
(Tg/yr)	Control	Topo_ Gnx1	Topo_ ASTmsk	Topo_ AST	Geom_ Zdr03	Stat_ MDB
Winter NDJFMA	968.23	69.51	209.68	276.74	13.93	19.74
Summer MJJASO	979.35	93.72	252.54	341.97	14.16	20.32
Annual	1947.57	163.23	462.23	618.71	28.09	40.06

Sensitivity of Spatial/Temporal Distribution of Emission Flux to Erodibility factor

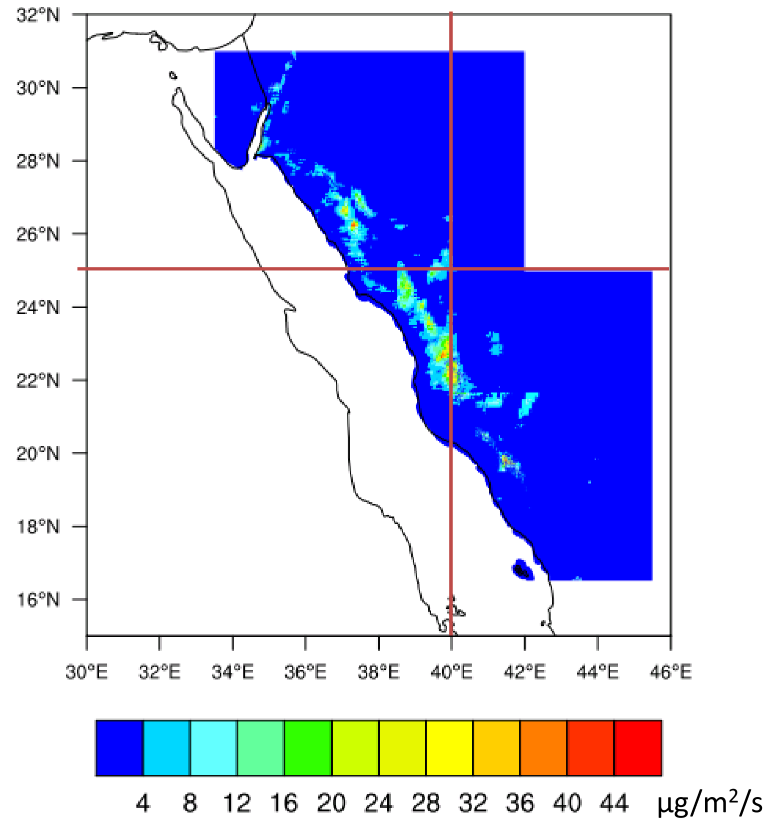
- Dust emission simulated based on topographic factor is negatively correlation with observations from all the NCDC visibility stations
- Both topographic and geomorphic factor results are well correlated with observation when the coastal samples are removed
- The simulations with the statistical factor compare better with observations in the coastal area than simulations using other erodibility factors

	R Model vs. reciprocal of visibility		R Model vs. MODIS DOD	
	With Coast	No Coast	With Coast	No Coast
Topo_Gnx1	-0.083	0.248	-0.269	0.335
Topo_AST	-0.049	0.232	-0.154	0.323
Topo_ASTmsk	-0.055	0.209	-0.149	0.373
Geom_Zdr		0.263		0.372
Stat_MDB	0.185	0.126	0.215	0.115
Control	0.133		0.097	

Spatial Distribution of Dust Emission during the Dust Event of Jan 2009

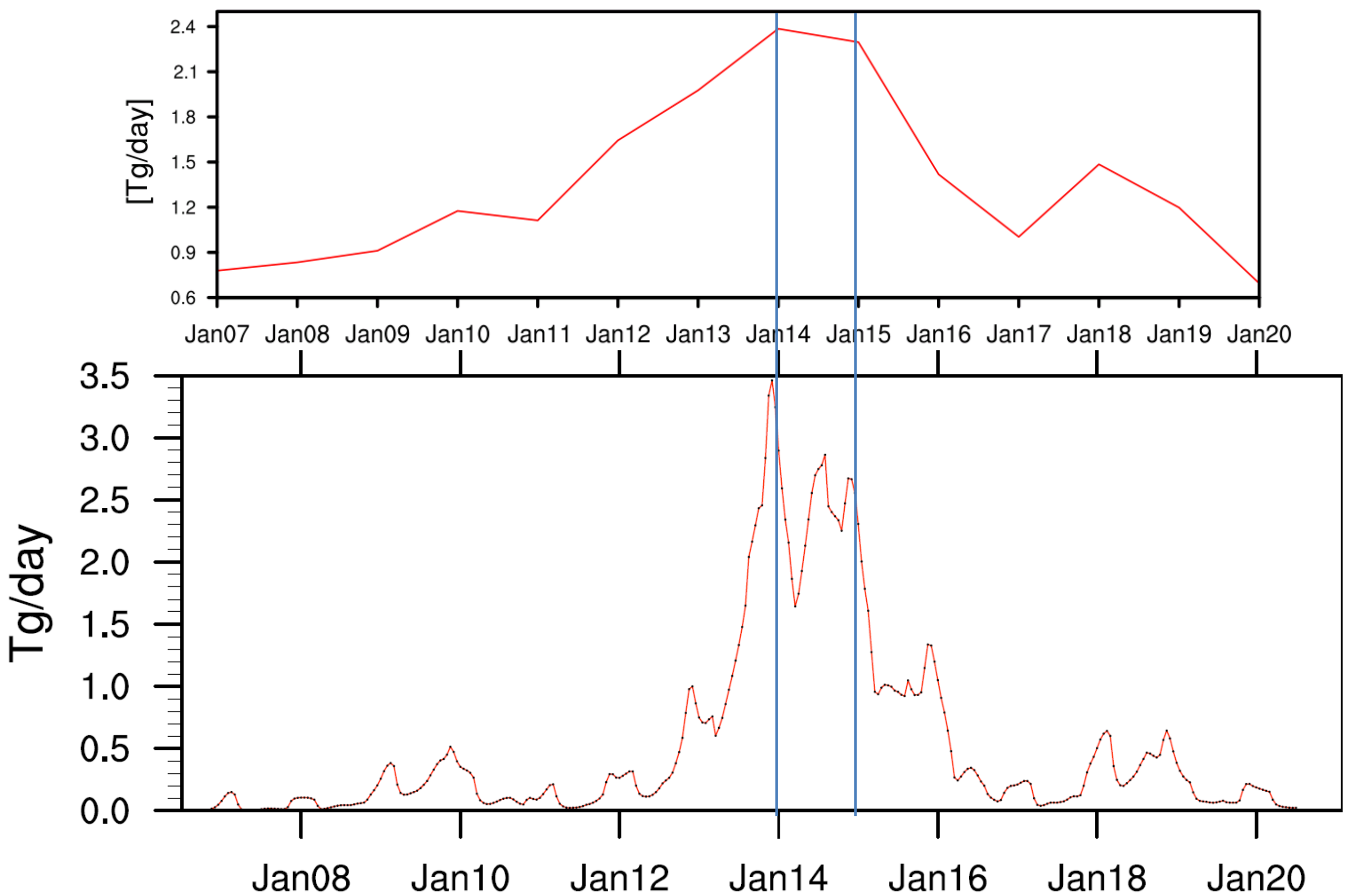


S. Kalenderski et al. 2013
10km x 10km



This Research
500m x 500m

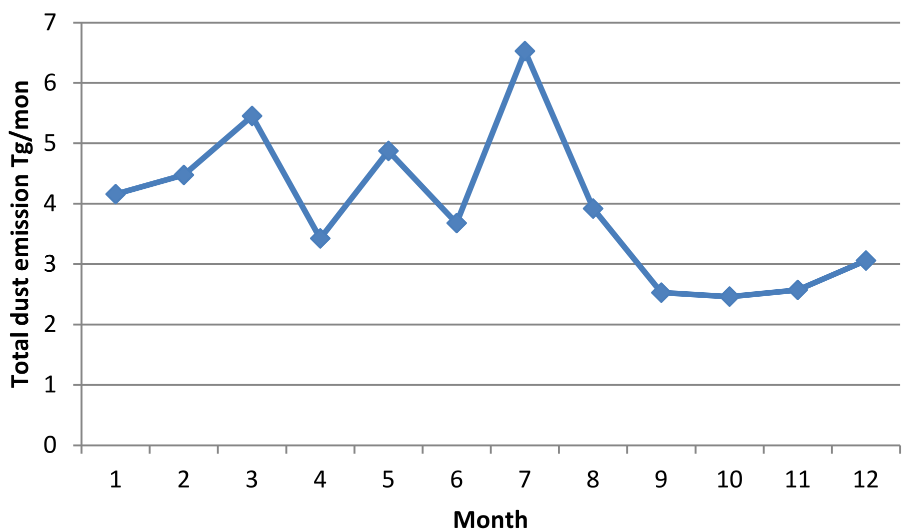
Temporal Evolution of **Dust Event** in Jan 2009

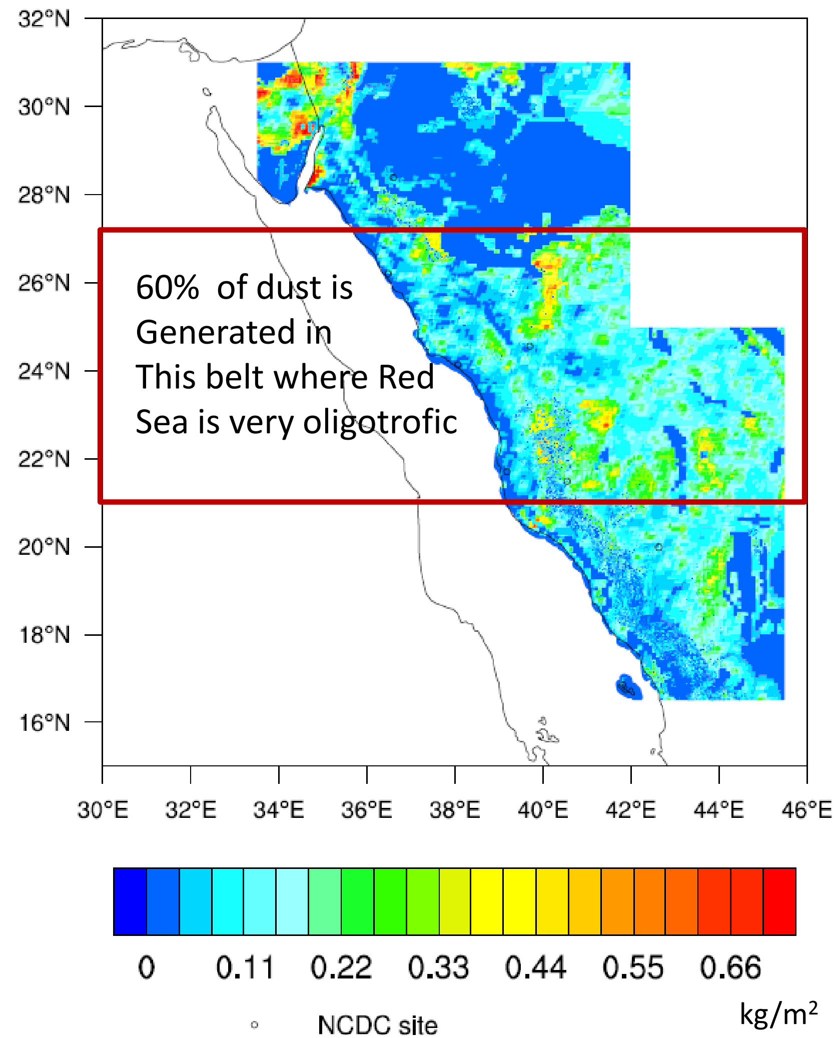


- Upper: S. Kalenderski et al. 2013 (daily); Bottom: This research (hourly)

Quantifying total dust emission

	Control	CASE2_MDB	CASE3_MDB
Winter NDJFMA	968.23	19.74	23.14
Summer MJJASO	979.35	20.32	23.99
Annual	1947.57	40.06	47.14





Conclusion

- High resolution model **improves the spatial/temporal distribution** of dust simulation, while produces more dust and increases variability of dust flux.

- To account for the land surface change in the dust model, we have to **update PFT and LAI simultaneously**.

- Source erodibility factor is particularly important for dust generation modeling.
  - The topographic and geomorphic factors perform well in heterogeneous area, but **fail in homogeneous coastal area**.
  - Statistical factor could give better results in such a region, especially when using a long term historical sampling record.
- The dust emission from the Red Sea coastal areas reaches about **47 Tg annually** which is higher than some other estimates. This might in part results from using high resolution model. Since the spatial distribution and temporal evolution of dust emission are quite good, the total flux could be tuned.
- 60% of dust is generated in the latitude belt of 21°N-27°N, where the Red Sea is especially oligotrofic.
- The global mineral soil database suggests that the dust generating soils at the Red Sea coast contain 20% Quartz, 20% Feldspar 20%, 10% Smectite, 8% Illite, 8% Calcite.