Desert Dust and Snow Darkening

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Mineral dust and high-altitude environments

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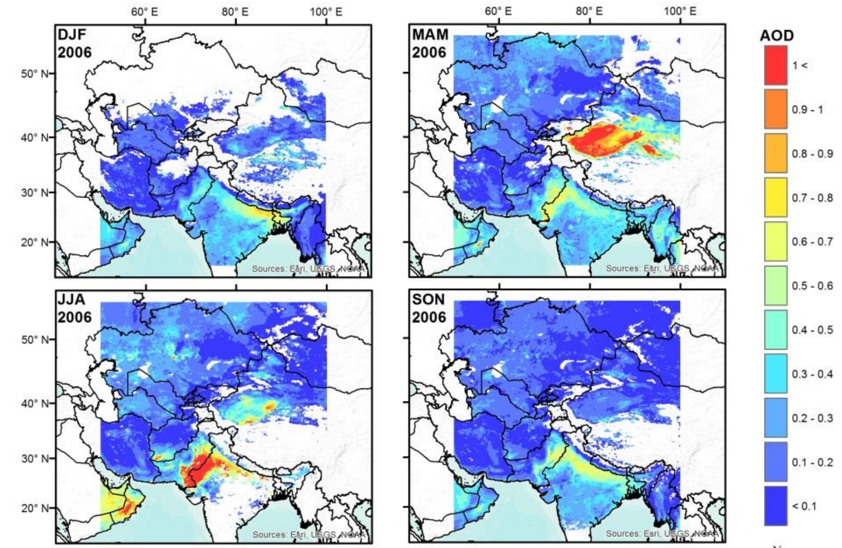
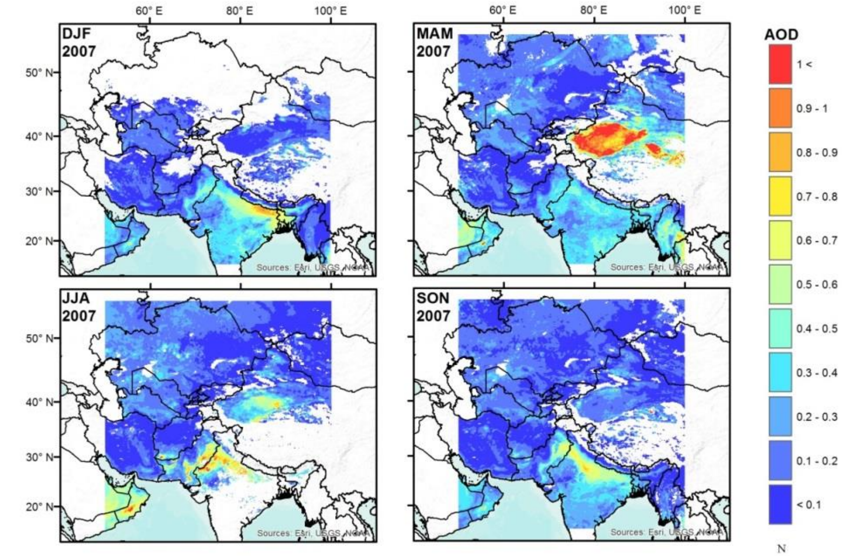
- Light-absorbing impurities (LAI)
  - Black carbon
  - Mineral dust produced locally
  - Mineral dust from deserts
  - Cryoconite
- At-surface radiative forcing
  - Direct: Absorption in VIS-NIR
  - Indirect: (i) Changes in snow grain size; (ii) enhanced melt and exposure of dark substrate; (iii) atmospheric heating (?)
- Dust as transportation vector for other pollutants: Combined RF and changes in geochemistry
- Dust in ice cores as indicator of environmental variability

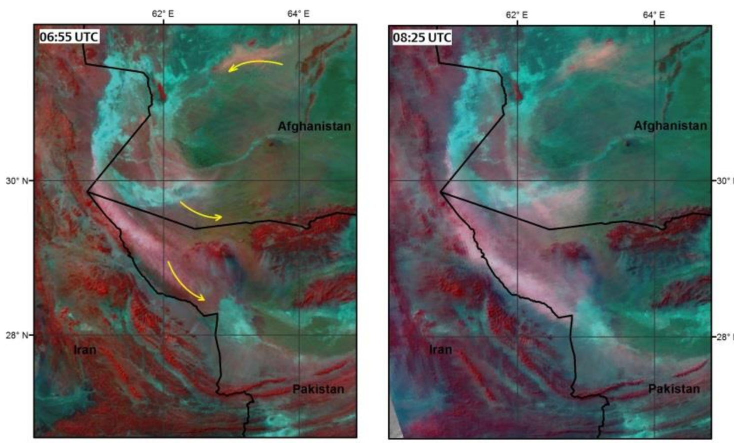
Atmospheric dust: MODIS Deep Blue AOD



Seasonal Changes of MODIS Deep Blue AOD at 550 nm in 2006



Seasonal Changes of MODIS Deep Blue AOD at 550 nm in 2007



Dust enhancement from MODIS Imagery aquired on 14 June 2006
06:55 UTC from MODIS/Terra (Left) & 08:25 UTC from MODIS/Aqua (Right)

GAW NCO-P
Bonasoni et al. (2010); Duchi et al (2011):
~ 67% westerly or south-westerly transport
Dust transport
~50% Lot & Thar; ~17% Arabian peninsula;
~16% Indo-Gangetic plain; Tibetan plateau and Taklamakan

Changes in spectral reflectance of snow and ice

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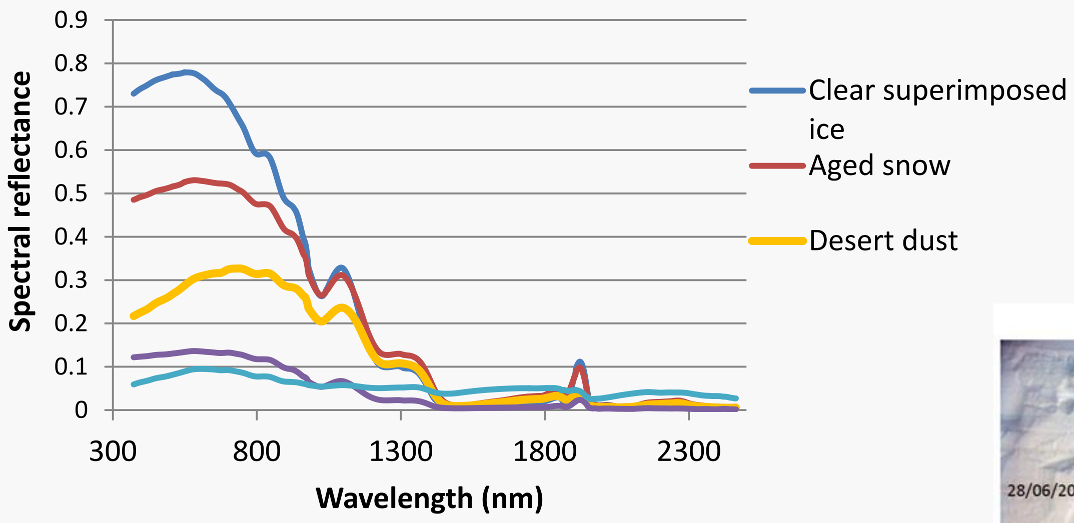

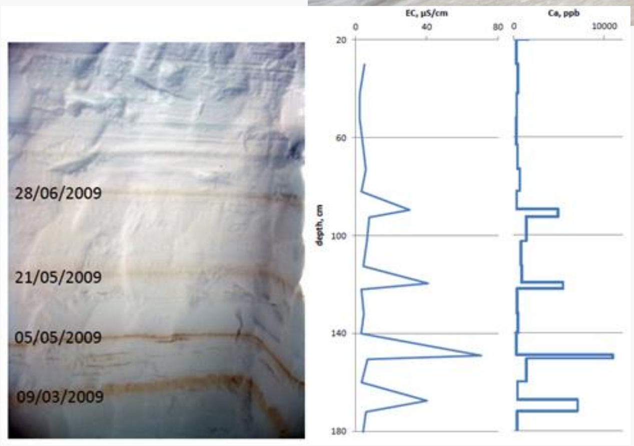

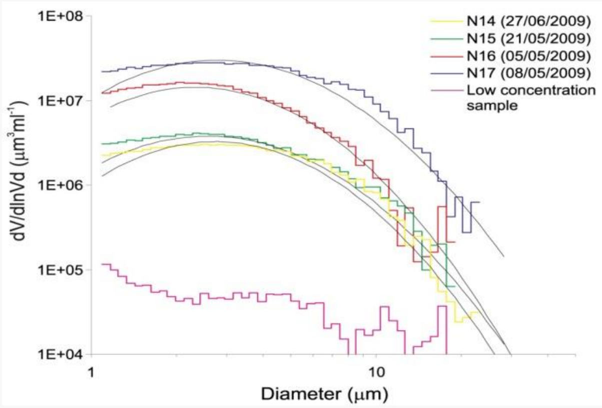

Desert dust enhances

- Absorption and VIS – NIR gradient
- Mass balance models: effect of 10% albedo reduction is equivalent to 1.5K warming
- Combined reflectance – micrometeorological – dust properties measurements needed for at-surface RF estimation and melt models

At-surface dust RF in the Himalayas and Tibet: Ice cores

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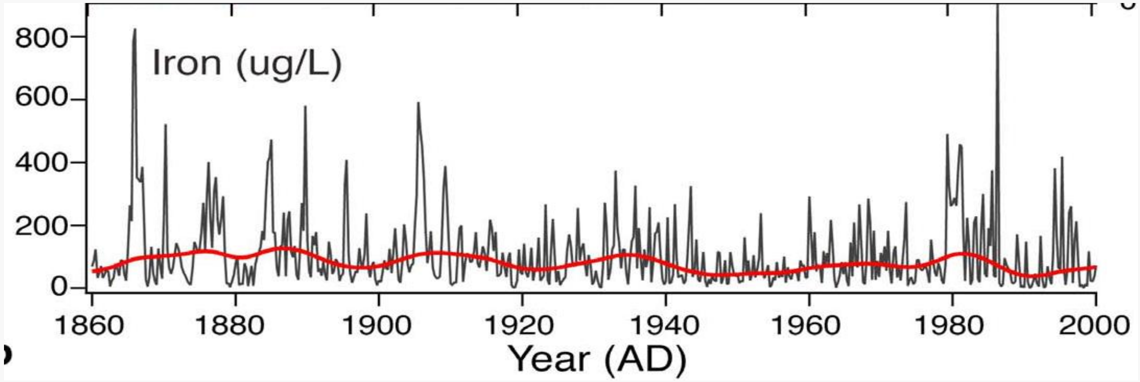
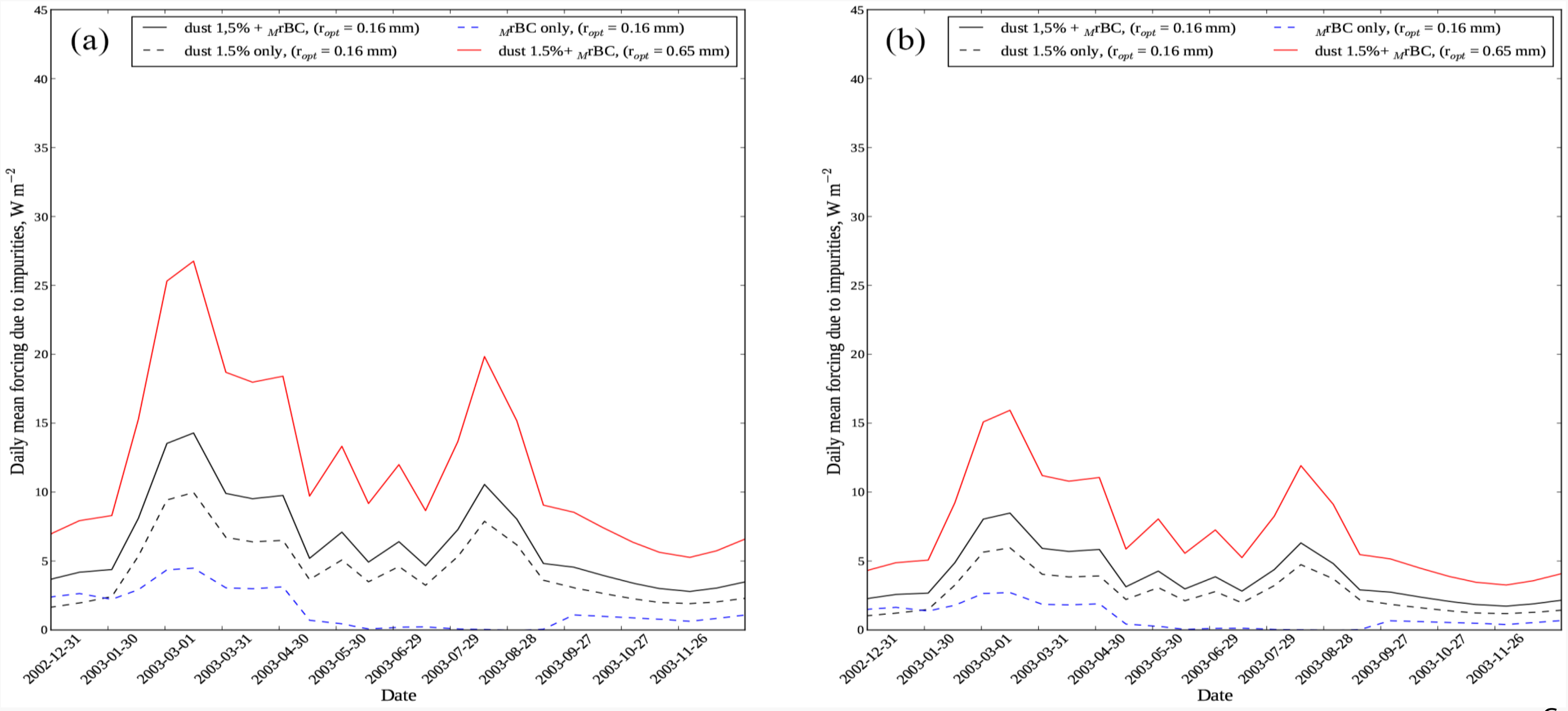
- Tompson et al. (1989, 1990, 2000) Tibetan Plateau
- Xu et al. (2010) East Rongbuk Glacier, Mt. Everest, 600-1960
- Kaspari et al (2011) East Rongbuk Glacier, Mt. Everest ice core 1860-2000
  - Assessment of combined BC and dust RF using SNICAR:
- Ginot et al (2014) shallow Mera Peak ice core, 2000-2010
  - Assessment of combined BC and dust RF using DISORT
- Dependence of dust RF on hematite content
- Non-linear changes in RF when considering combined BC + dust effect

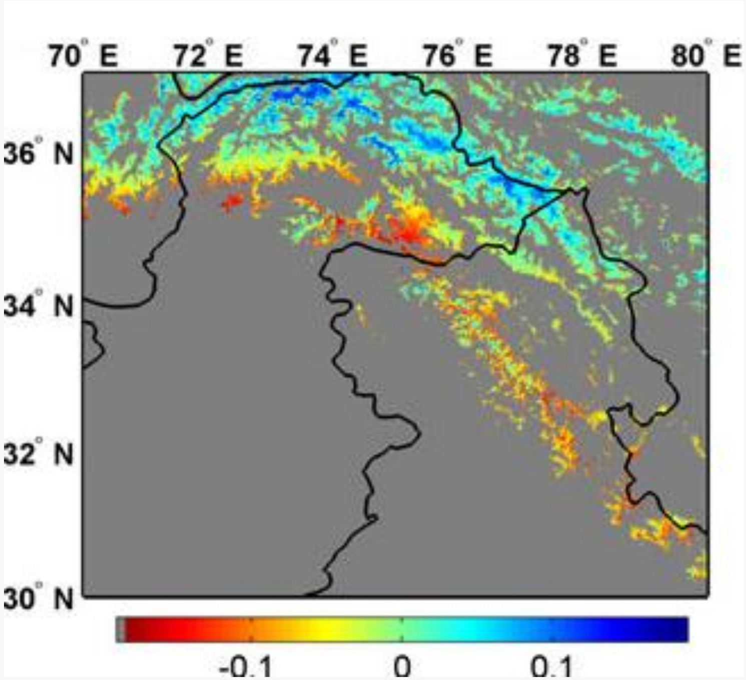


Kaspari et al., 2009

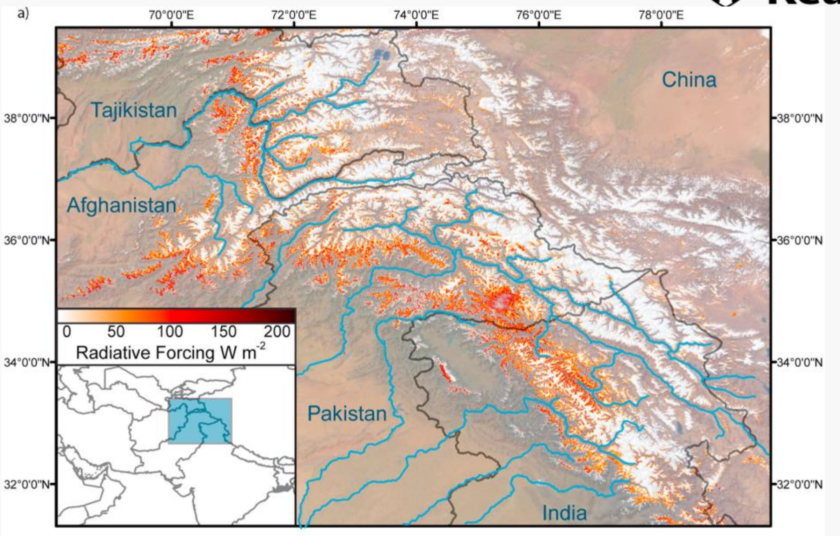
Daily mean forcing due to LAI under clear sky and cloudy sky conditions in 2003 for different combinations of LAI (Ginot et al., 2014)



Retrieval of at-surface dust RF using MODIS



Difference between MODIS $R_{0.47}$ and $R_{0.86}$ 6-15 June 2003; negative values indicate presence of desert dust (Gautam et al., 2013).

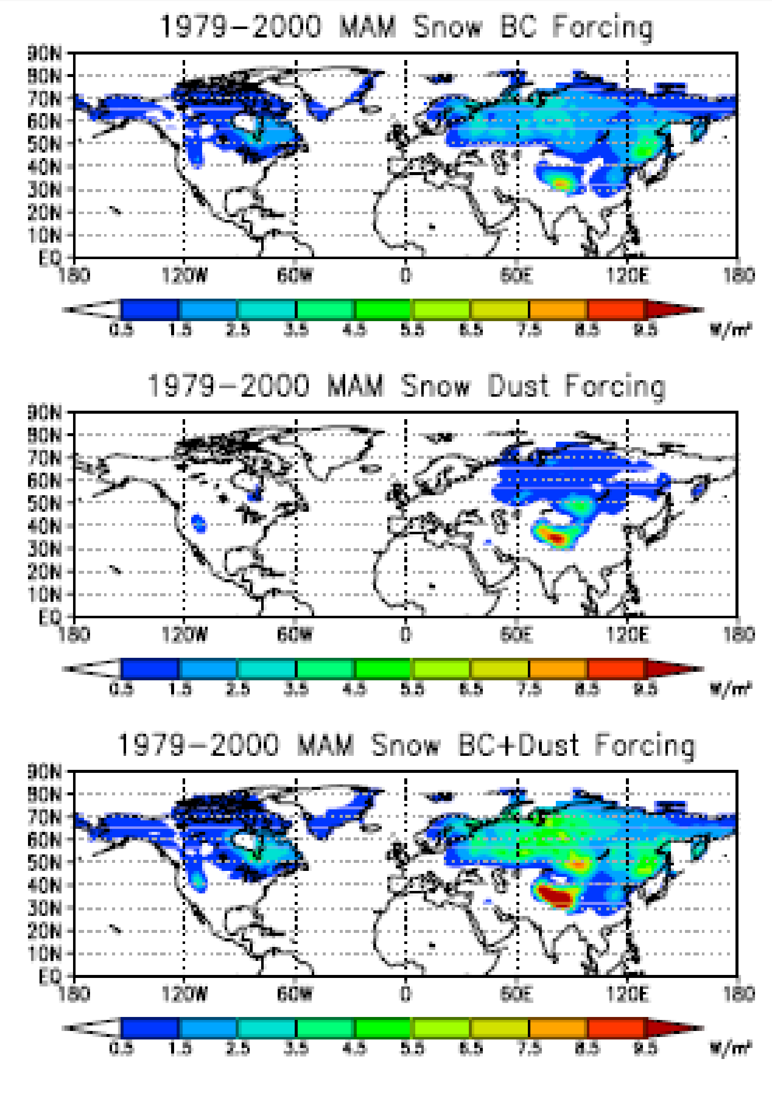


MODRRFS: Dust radiative forcing in snow for Hindu Kush-Himalaya on 21 June 2010 (Painter et al., 2012)

Uncertainties: sensor properties, atmospheric dust, snow properties and surface roughness, sub-pixel terrain: Ground truth required

What is the effect of dust deposition on glacier retreat in the western Himalayas?

At-surface dust RF in GCM



NCAR Community Atmosphere Model using SNICAR to treat LAI (Flanner et al., 2009)

How well are source regions and pathways known?

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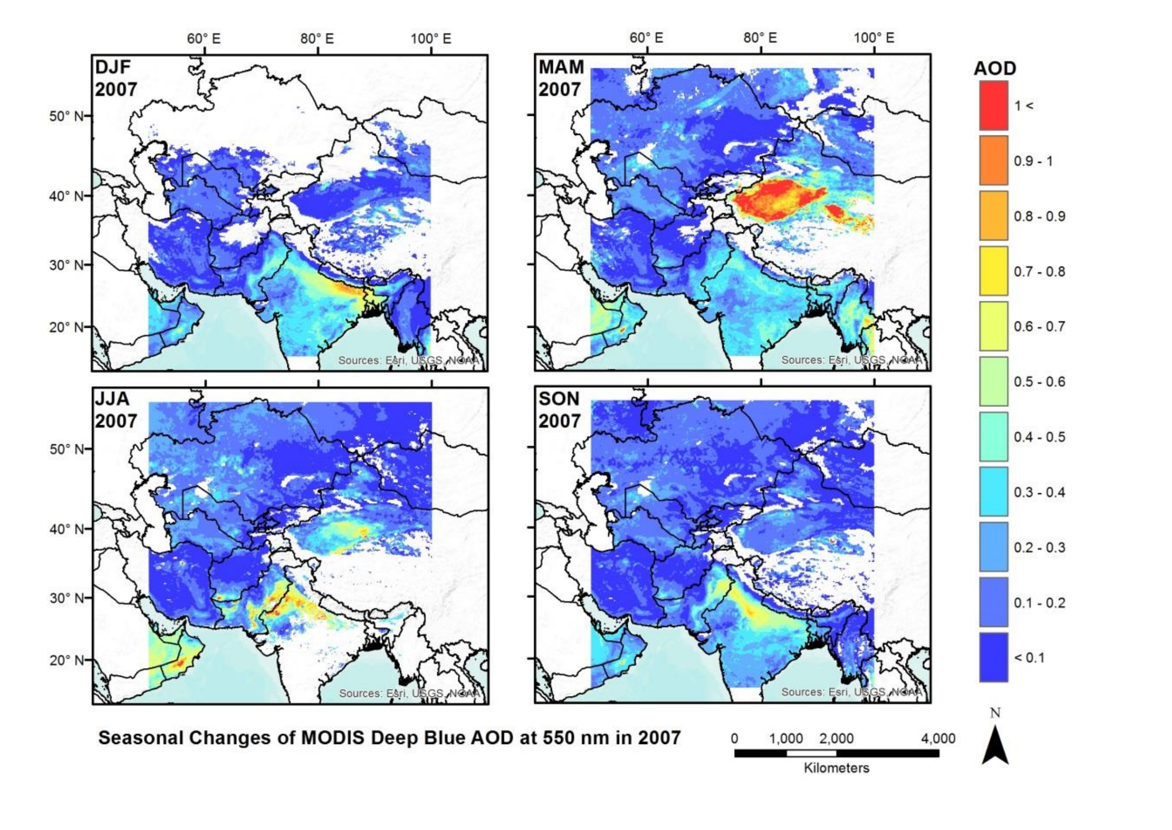
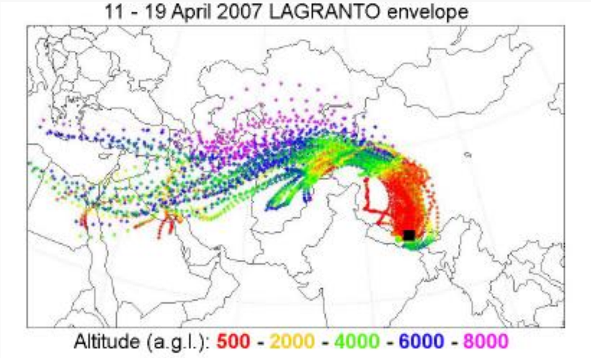
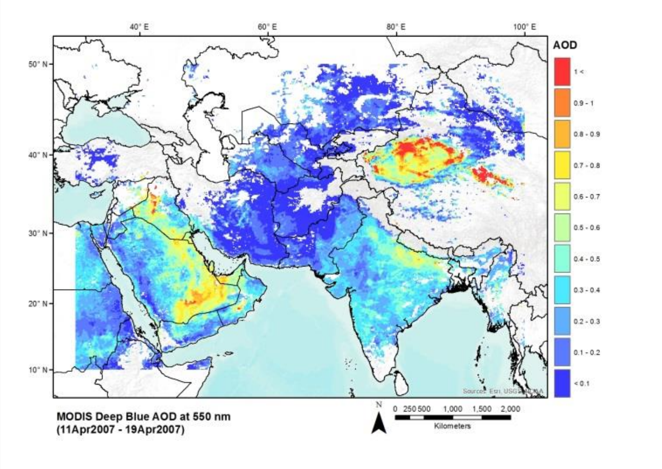
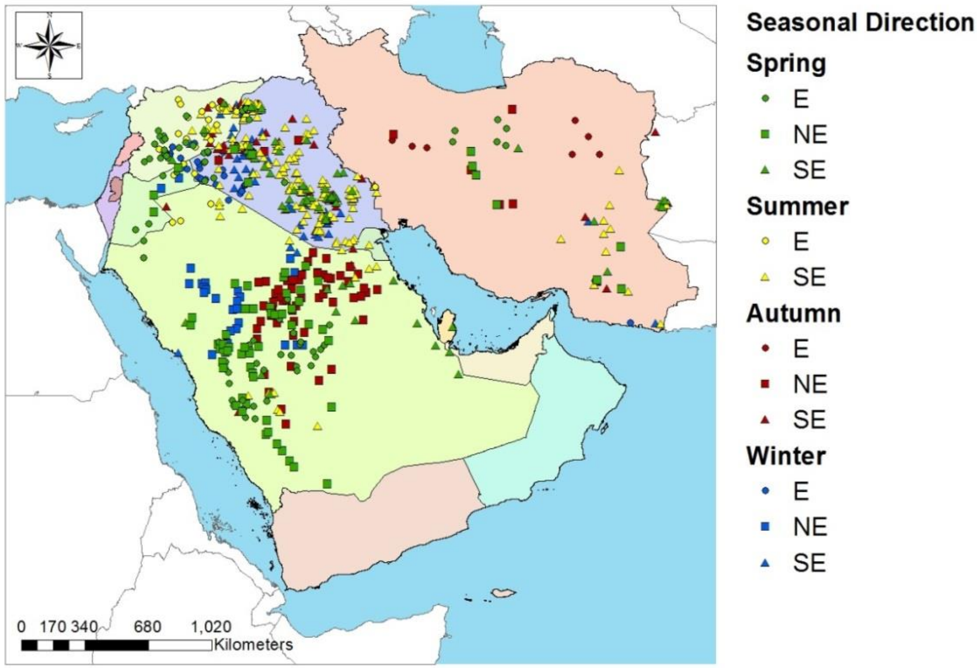




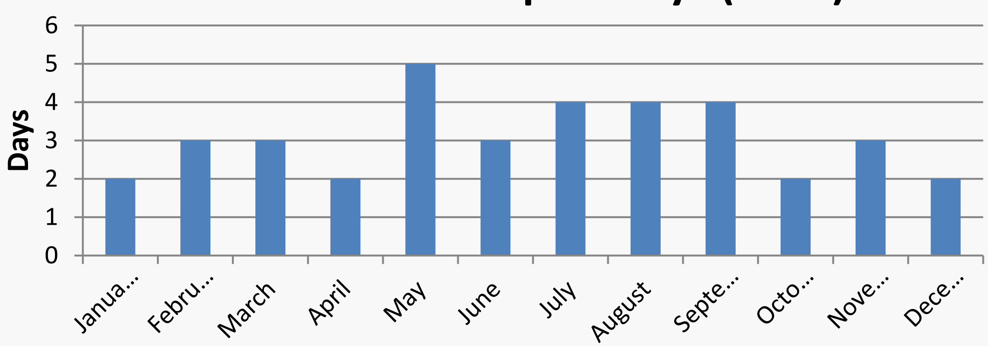


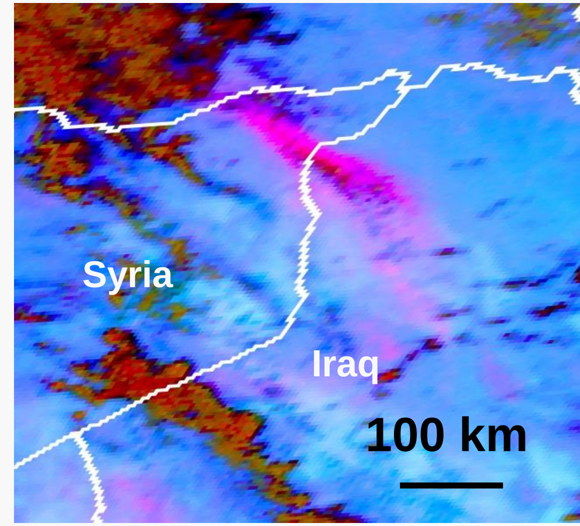
Analyses based on back trajectories for NCO-P (e.g. Bonasoni et al, 2010; Duche et al., 2011); ice cores (e.g. Kaspari et al., 2011) and qualitative interpretation of AOD (e.g. Prasad et al., 2011).

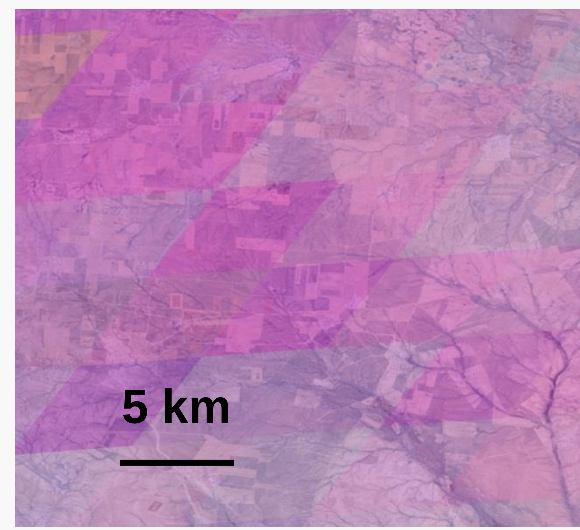
Emission events contributing to dust transport towards the Himalayas: SEVIRI MSG



Number of dust transport days (2007)







Conclusions

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- Although RF of dust is weaker than that of BC, it appears to have strong regional signal potentially resulting in stronger and earlier melt
- Many open questions concerning at-surface dust RF
- So far few studies but growing field; few observations to validate models and satellite data; combined approach is required