# 16th Weather Squadron

*Fly - Fight - Win*

# AFWA DUST

## EMISSION SCHEME

### for WRF-Chem/GOCART

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**Aerosols/Fine Scale and Ensemble Models**
**16 WS/WXE &WXN**

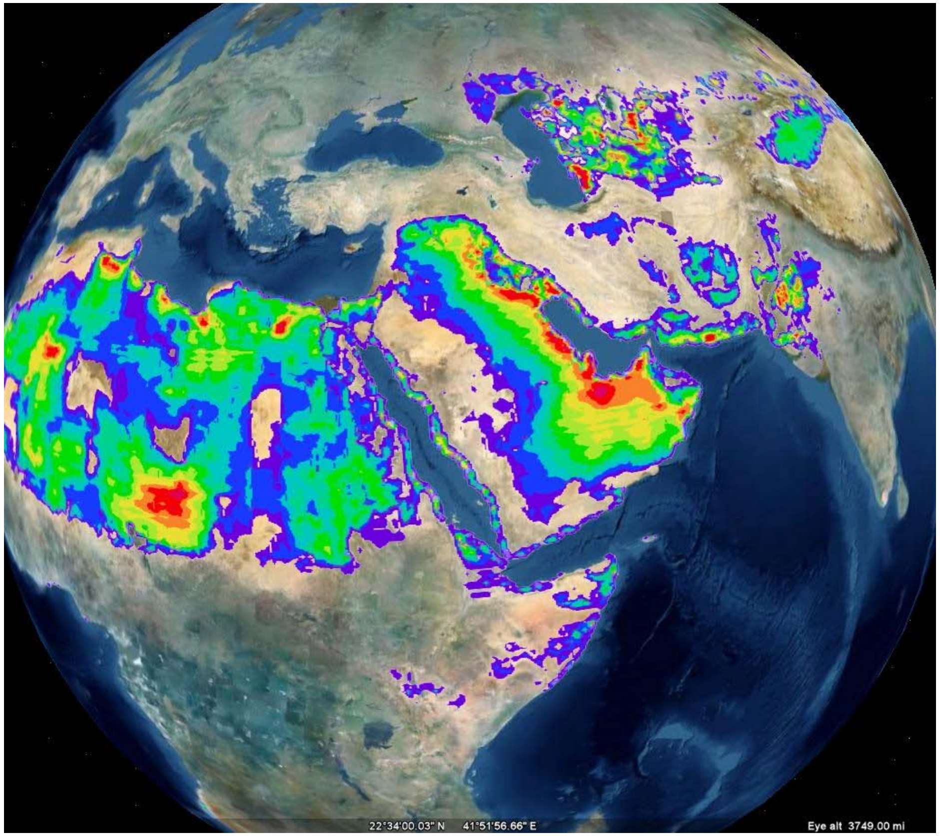
# Outline

**<u>Outline of Talk</u>**

- **Erodibility databases**
- **Dust emission 101**
- **Possible causes of error in the original GOCART emission scheme**
- **Emission scheme rewrite used by AFWA**

# Topography Based Erodibility

## Ginoux Erodibility Factor




- **Assumes loose sediment accumulates in topographic depressions.**
- **Calculates elevation relative to surrounding area within a 10° range.**

$$S = \left(\frac{z_{max} - z_i}{z_{max} - z_{min}}\right)^5$$

$S$ = probability of having accumulated sediments at grid cell $i$

$z_{max}$ = maximum elevation in the surrounding topography

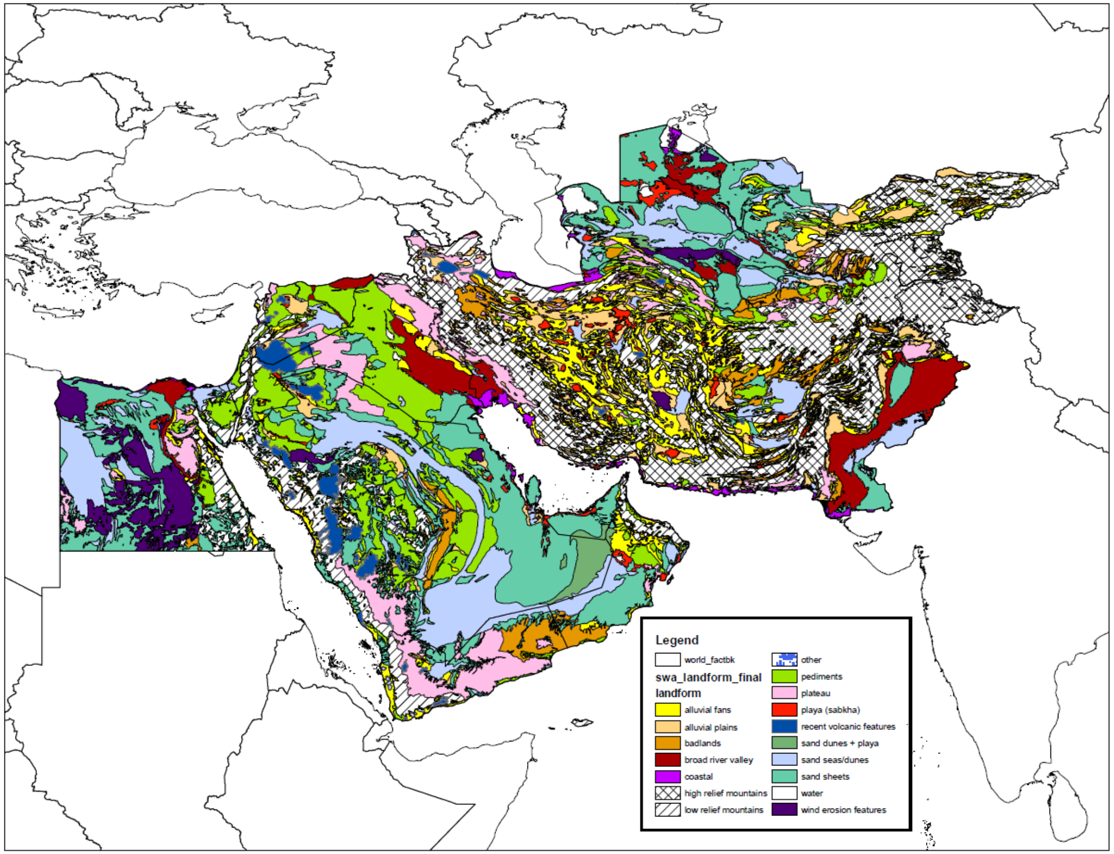
$z_{min}$ = minimum elevation in the surrounding topography

$z_i$ = elevation at grid cell $i$

**Assumes Holocene lake beds are primary sources of dust!**

# Landform Based Erodibility

## Southwest Asia Landform Map (Desert Research Institute (DRI))




**AFWA and DRI developing physical process based erodibility database!**

# Dust Emission 101

# Dust Basics

- Dust is not usually lofted directly by the wind!

- Cohesive Forces
  - Soil moisture tensile force/matric suction, electrostatic forces, chemical binding, etc.
  - Hold soil grains to the ground.
  - Stronger than aerodynamic forces for particles < ~ 80 μm

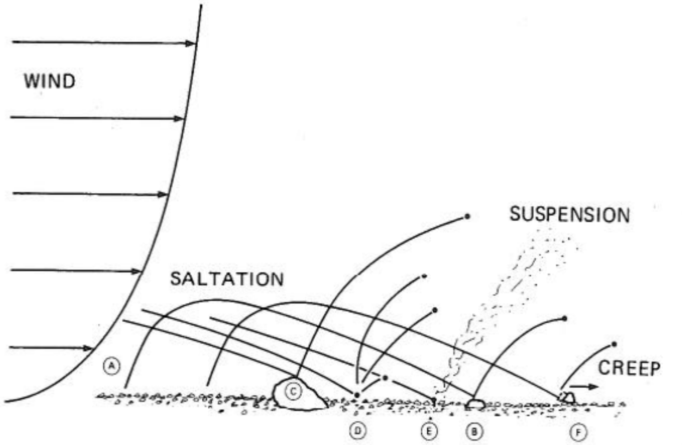
- Dust Particles
  - Typically < ~ 50 μm
  - Most are < ~ 20 μm

# Dust Basics

- **Dust lofting is typically caused by ballistic sandblasting!**

- **Lofting Process:**
  - **Wind transfers momentum to relatively easy to move sand grains.**
  - **Sand particles are too heavy to remain airborne for long: they fall back toward the surface after rising ~ 1 m. (Commonly referred to as saltation.)**
  - **Upon collision with the SFC, sand particles**
    1. **Become embedded in the particle bed**
    2. **Cause a cascading effect ejecting more sand grains (saltation flux)**
    3. **Or smash up dirt clods spraying “dust” sized particles into the air (sandblasting).**

**Dust Production**




(Source: Greeley and Iversen, 1985)

# Dust Basics

- To adequately model dust production processes, an emission scheme must accurately predict:
- (1) the threshold friction velocity* required for soil particle mobilization;
- (2) the horizontal saltation flux used to transfer momentum from the wind to the soil; and
- (3) the vertical flux of dust (efficiency of sandblasting).

❖ Point where enough energy has been transferred from the wind to a grain to get it moving.

# Original Dust Flux EQ

- **GOCART Dust flux EQ according to Ginoux et al. 2001 & 2004**

$$F_p = \begin{cases} C S s_p U^2 (U - U_t) & \text{if } U > U_t \\ 0 & \text{otherwise} \end{cases}$$

**Where:**

$F_p$ = Vertical Dust Flux for Particle Bin
$C$ = Dimensional Tuning Constant
$S$ = Erodibility Fraction
$s_p$ = Particle Bin Mass Fraction
$U$ = 10 Meter Wind Speed
$U_t$ = Threshold 10 Meter Wind Speed

- **$U^3$-driven saltation scheme**
- **Tegen and Fung (1994) added $s_p$ parm. (Table 1 T&F article; α parm.)**
- **Added an erodibility term (S)**

# Original Dust Flux EQ

- **GOCART Dust flux EQ**

$$F_p = \begin{cases} C S s_p U^2 (U - U_t) & \text{if } U > U_t \\ 0 & \text{otherwise} \end{cases}$$

**Where:**

$F_p$ = Vertical Dust Flux for Particle Bin
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$U$ = 10 Meter Wind Speed
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- **Supposed to include a soil separate mass fraction (Tegen and Fung, 1994).**
- **Step missing from 2001 GOCART scheme.**
- **Later addition to GOCART code: split erodibility fraction into 3 classes (dist. 0.5/0.25/ 0.25) associated with sand, silt and clay classes.**
- **Essentially, all erodible lands have a 50% sand, 25% silt, and 25% clay soil composition. – Not realistic!**

# Original Dust Flux EQ

- **GOCART Dust flux EQ**

$$F_p = \begin{cases} CSs_pU^2(U - U_t) & \text{if } U > U_t \\ 0 & \text{otherwise} \end{cases}$$

**Where:**

$F_p$ = Vertical Dust Flux for Particle Bin
$C$ = Dimensional Tuning Constant
$S$ = Erodibility Fraction
$s_p$ = Particle Bin Mass Fraction
$U$ = 10 Meter Wind Speed
$U_t$ = Threshold 10 Meter Wind Speed

- **Parameter mix up. Equations cited for threshold velocity are actually equations meant to calculate threshold friction velocity ($u_{*t}$).**
- **Ginoux et al. 2001/original scheme:**
  - **EQ for dry soil $u_{*t}$ from Bagnold (1941).**
- **Ginoux et al. 2004/WRF-Chem v3.3 GOCART code:**
  - **EQ for dry soil $u_{*t}$ from Marticorena and Bergametti (1995).**

**No conversion between $U_t$ and $u_{*t}$.**

# Original Dust Flux EQ

- **Actual EQ being calculated**

$$F_p = \begin{cases} C S s_p U^2 (U - u_{*_t}) & \text{if } U > u_{*_t} \\ 0 & \text{otherwise} \end{cases}$$

- **Although they have the same units, the magnitude of 10 m winds >> than its equivalent friction velocity.**
- **Because of this error, Ginoux et al. applied the saltation algorithm to dust- sized particles rather than sand-sized particles.**

**Issues**

- Sandblasting component missing.
- Small particles loft directly by wind.
  - **Clay sized material lofting with 2-3 kt winds (50-60 kt winds in actuality).**
  - **Essentially, erodibility term and soil moisture threshold are the only emission restriction controls.**

**This explains why this scheme will give you reasonable output for synoptic events with strong forcing at coarse resolutions and high FAR under light winds.**

# AFWA Emission Scheme

# AFWA Scheme

- **Bulk Vertical Dust Flux Scheme: Based on Marticorena & Bergametti (1995)**
  - **Threshold Friction Velocity (Iversen & White, 1982)):**

$$u_{*_t}(D_p) = 0.129 \frac{\left[\frac{\rho_p g D_p}{\rho_a}\right]^{0.5}\left[1 + \frac{0.006}{\rho_p g D_p^{2.5}}\right]^{0.5}}{\left[1.928\left(aD_p^x + b\right)^{0.092} - 1\right]^{0.5}}$$

$$u_{*_t} = u_{*_t}(D_p)\,\frac{f(\text{moisture})}{f(\text{roughness})}$$

  - **Saltation Flux Over Bare Soil (Kawamura, 1951):**

$$H(D_p) = C\frac{\rho_a}{g}u_*{}^3\left(1 + \frac{u_{*_t}}{u_*}\right)\left(1 - \frac{u_{*_t}{}^2}{u_*{}^2}\right)$$

$$G = \sum H(D_p)\,dS_{rel}(D_p)$$

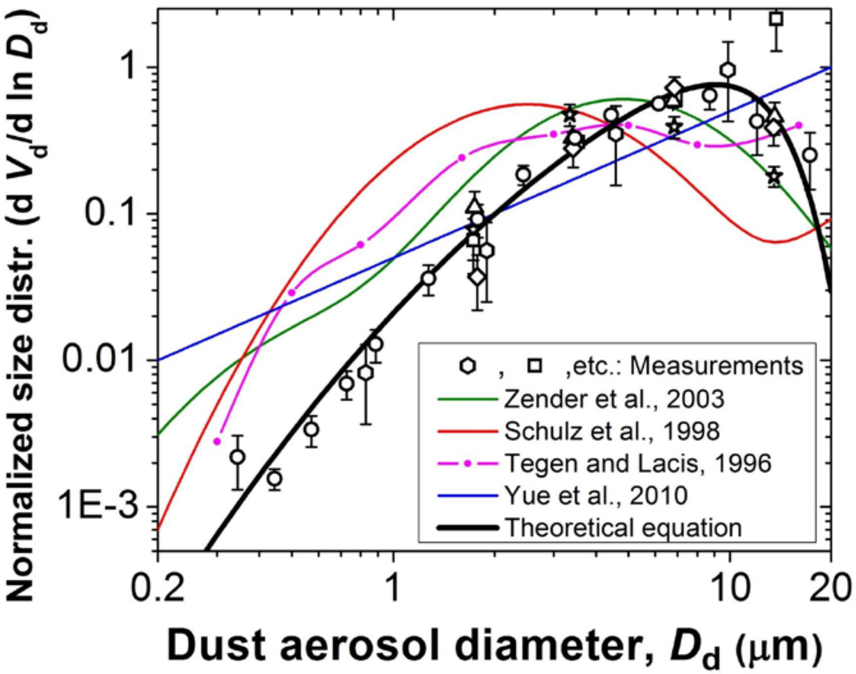
  - **Bulk Vertical Dust Flux (efficiency factor (α): Gillette, 1979)**

$$F_{bulk} = G\alpha \times \text{Erod}$$

$$\alpha = 10^{0.134(\%\text{clay})-6}$$

# AFWA Scheme

- **Marticorena and Bergametti scheme only provides bulk dust flux.**
- **Particle Size Distribution (PSD) developed by Dr. Jasper Kok (NCAR)**
  - **Brittle material fragmentation theory**
  - **Kok, 2010 (PNAS)**

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# Threshold Friction Velocity

- Correction factors applied to $u_{*t}$,

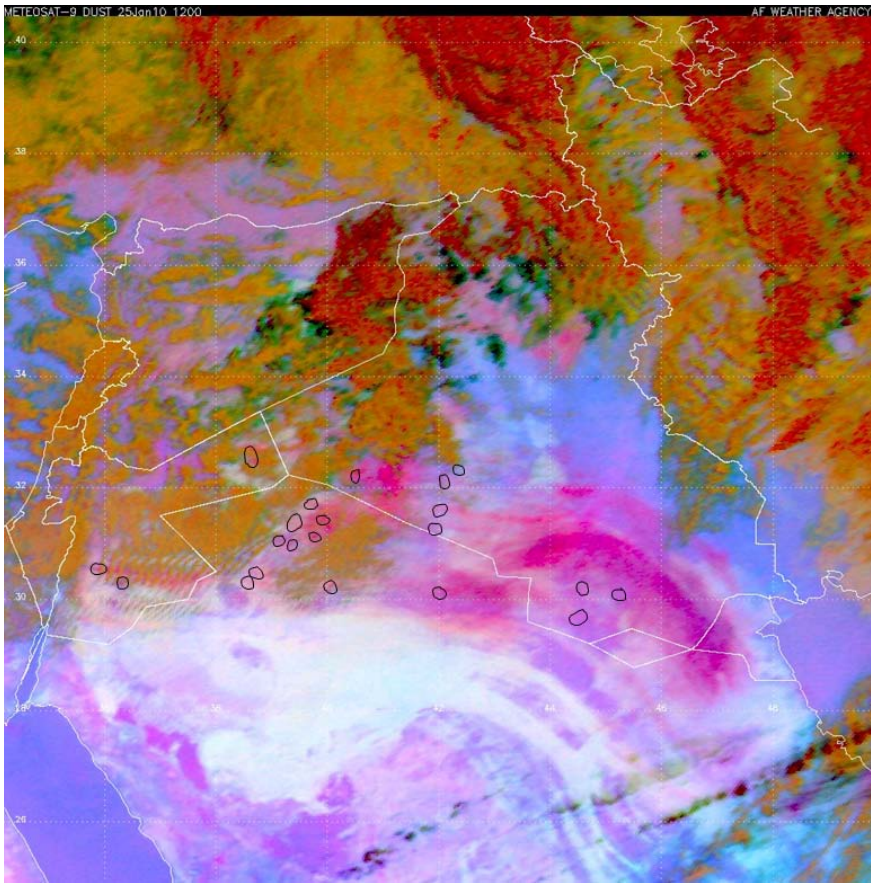
$$u_{*t} = u_{*t}(D_p)\,\frac{f(\text{moisture})}{f(\text{roughness})}$$

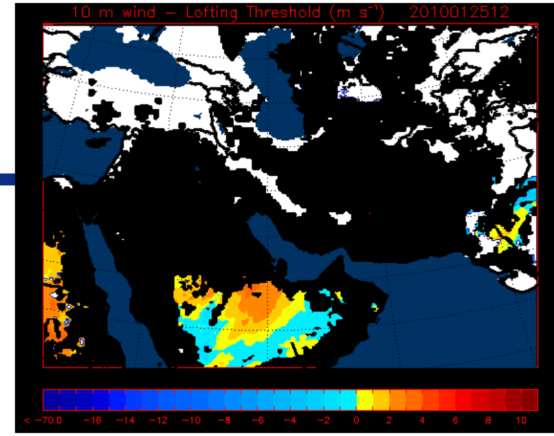
- $f(\text{roughness})$ is a drag partition correction
  - $f(\text{roughness}) = 1.0$ implies the surface is smooth; value decreases with increasing amounts of large rocks, cobbles, vegetation, etc.
  - Currently set to 1.0; representative of Southwest Asia.
  - Dust emission is restricted to areas with roughness length $z_0 \leq 5$m (typically barren lands and sparsely vegetated surfaces).

# $f$(moisture)

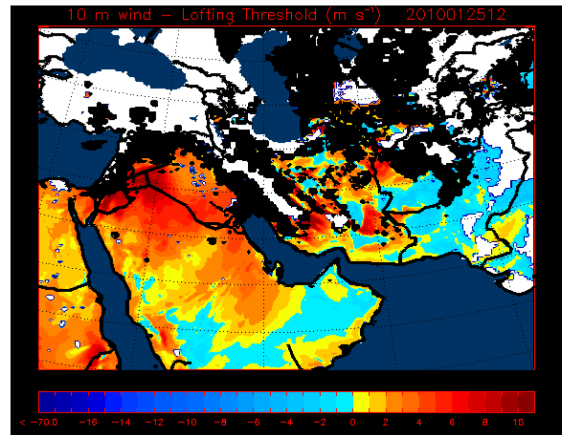
- $f$(moisture) accounts for tensile force and apparent cohesion
- Calculated using the Fécan method (Fécan et al., 1999).
  - Increases $u_{*_t}$ as soil moisture increases
  - Incorporates soil texture.
    - Clayey soils typically hold more hygroscopic water than sandy soils.
      - Clay particles are smaller than sand particles.
      - More surface area to spread water over.
    - Clayey soils remain "air dry" longer than sandy soils as soil moisture increases.

## Dust Enhanced METSAT-9

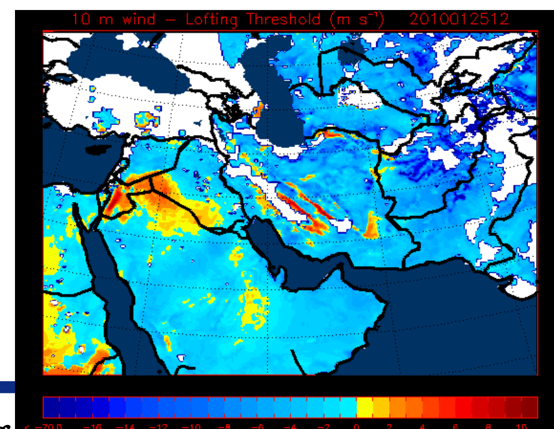



**20% Deg Sat**

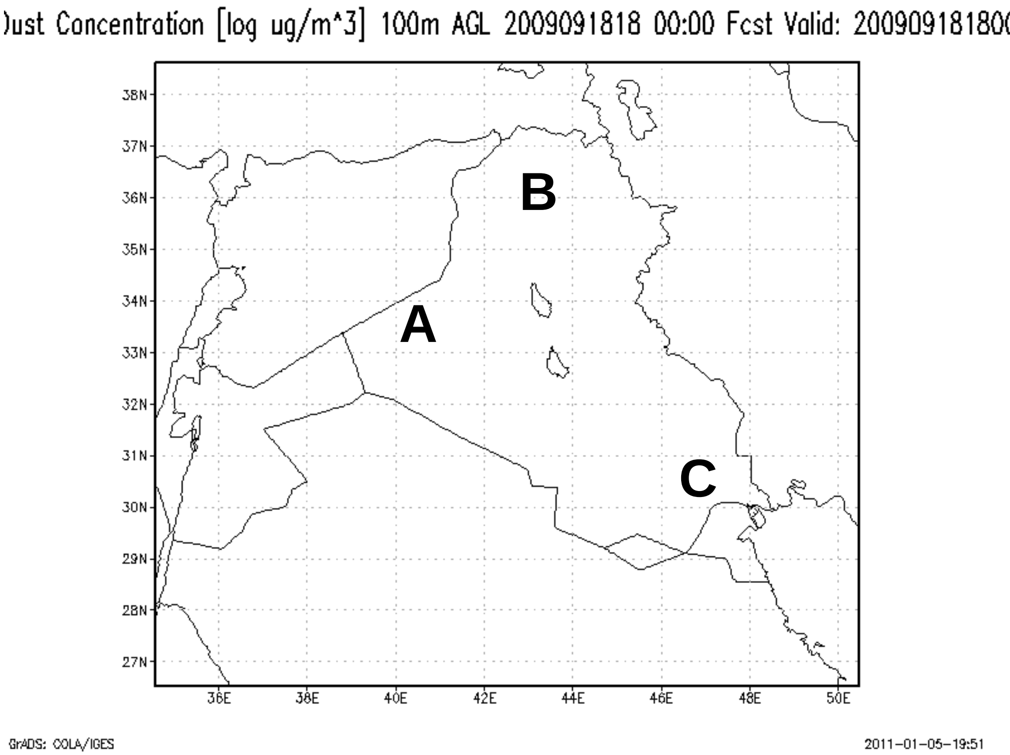


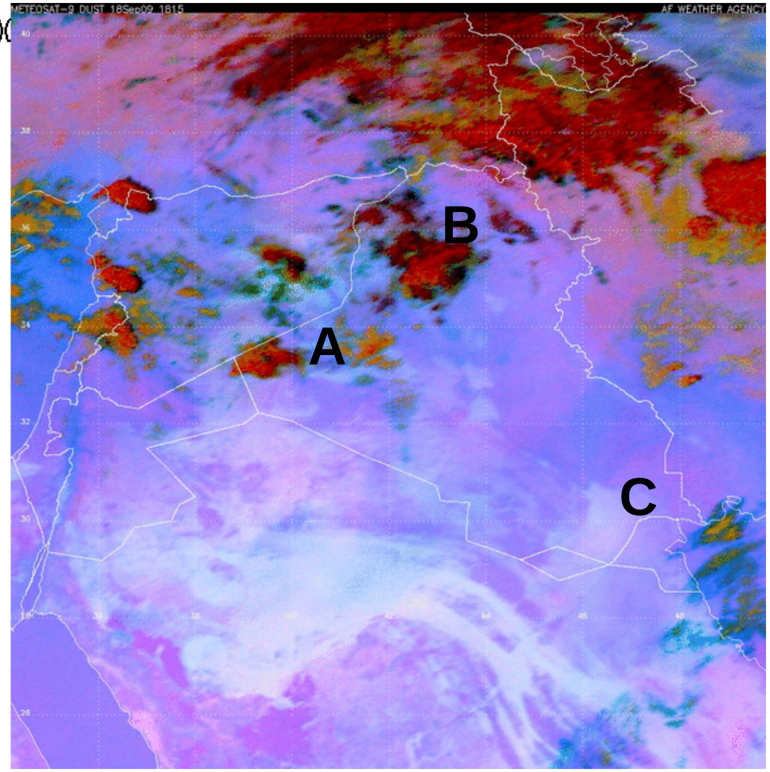

**50% Rel Smois**




**Fecan Method**

# CAND-E




A--Convective activity mid-simulation
B—Mesoscale wind perturbation
C– Sea breeze front from Persian Gulf

## Convective Allowing Numerical Dust - Ensemble

# Questions?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