EYES IN THE SKY: AN AQUA-BASED CHARACTERIZATION OF
THE SAHARAN AIR LAYER

Stephen D. Nicholls (JCET/GSFC)
Karen I. Mohr (GSFC)
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NORTH AFRICA'S COMPLEX CLIMATE SYSTEM (1)

Vast piece of real estate
- Spans Equator to 39N, 20W to 50E

Diverse ecosystem
- Rainforests to savannas to Desert
- Sahara 9.4 million km² ~ US

Diverse topography (Sea-level to 3000m+)

Source: dailymail.co.uk

Messager et al. 2009
NORTH AFRICA'S COMPLEX CLIMATE SYSTEM (2)

Monsoon (ITCZ)

Mid-latitude Systems

Strong Thermal Contrasts (AEJ)

Aerosol-cloud interaction

West African Monsoon

African Monsoon Peak: OLR, 200 hPa Streamlines, 850 hPa Wind Climatology (1979-1999)

Thunderstorm in Burkina Faso

Sahara ECMWF 07/01/2009 12UTC

Guinea Coast ECMWF 11/02/2009 12UTC
NORTH AFRICA'S COMPLEX CLIMATE SYSTEM (3)

• Annual precipitation pattern characteristics
• Saharan heat low
• Saharan Air Layer (SAL) - next

Abidjan, Ghana

Bamako, Mali
SAHARAN AIR LAYER (SAL)

Well-mixed layer of warm, dry, and dusty air of nearly constant mixing ratio generated by the intense surface heating and strong, dry convection in the Sahara Desert

- M’bourou et al. 1997; Karyampudi et al. 1999

Influence far and wide-ranging (Spanning Africa to Americas)

Dust impact: Direct (solar rad), indirect (CCN)
SO WHAT AM I RESEARCHING?

**Hypothesis:** NASA’s Atmosphere Infrared Sounder (AIRS) can detect well-mixed layers (WML’s) and SAL’s

**Gain:** Detection of SAL’s from space with regional coverage, consistent dataset quality

13 year period (2003-2015), 55 Stations

Data: L2 AIRS V6, L2 AIRS/AMSU V6, ECMWF-Interim, Rawinsondes
AIRS AND WELL-MIXED LAYER DETECTION ALGORITHM(1)

- Pressure: $\geq 500$ hPa & Mixing ratio: $\leq 7$ g kg$^{-1}$
- Log decrease in allowable constant mixing ratio deviation with height: (starting: $0.95$ g kg$^{-1}$ km$^{-1}$)
- Two calculations (temps and mixing ratio):
  1. Bottom of layer ($n_o$) to current level ($n$)
  2. Level below ($n-1$) to current level ($n$)
- If 1 and 2: same layer; if 2 only: new layer; otherwise: no layer
AIRS AND WELL-MIXED LAYER DETECTION (2)

- WML detection, not just Sahara
- Unable to resolve truly “thin” WML (vertical resolution)
- AIRS can sometimes best ECMWF
- WML detection frequency higher in winter months
WELL-MIXED LAYER ANALYSIS (1): DETECTION

Statistics over all 55 Stations (2003-2015)

Strong seasonality (higher winter)

Threat Score (TS): 0.35 AIRS, 0.42 ECMWF.

Highest Sahara, lowest coastal

FAR consistent between all data

- ECMWF over-biased (Mean 1.1)
- AIRS and AIRS+AMSU under-biased (0.6)
- Saharan detection rates: AIRS (60%), ECMWF (80%)
- Coastal detection rates: AIRS (20%), ECMWF (25%)
WELL-MIXED LAYER ANALYSIS (2): THICKNESS

- WML Thickness (2003-2015)
- Aqua AOD-based bins
- WML thickness: < 50 m to > 3000 m
- Thickness-Dust: limited dependence

ECMWF: Capture depth variance, under-biased

AIRS: More limited skill with depth variance, under-biased

Detection threshold: 300 m
HYSPLIT

- Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT)
- NOAA Air Resources Laboratory (ARL)
- ECMWF Interim Analysis, 5-day backwards trajectories
- Track parcels every 200 m in WML

SAL Classification Rules

1) Trajectory is Saharan:
   - 2 consecutive days in Sahara
   - 24 hours in Sahara within 72 hours of detection
2) WML is SAL: >50% of all trajectories are Saharan
   - Examples (see below)

Non-Saharan

Saaharan

Source * at 15.28 N, 38.92 E

Source * at 15.28 N, 38.92 E
SAHARAN AIR LAYER ANALYSIS (1): NON-SAHARAN

- Threat score (see right): Avg 0.4;
- General: AIRS > ECMWF, seasonal signal (dust extent)
- SAL thicknesses (bottom)
  - 300 m detection threshold
  - Limited dependence to dust (Aqua Deep Blue)
- ECMWF & AIRS: Similar thickness variance and IQR ranges

Radiosondes

**ECMWF**

**AIRS+AMSU**

Threat Score

Dates (yy/mm)

ECMWF  AIRS  AIRS+AMSU

Reduction in Radiation (1-transmittance)

SAL Depth (m)

<1.0%  1.0%-5.0%  5.0%-10.0%  10.0%-20.0%  20.0%-40.0%  40.0%-70.0%  >70.0%

0  1000  2000  3000  4000  5000  6000
Saharan Air Layer Analysis (2):

Threat score (see right): Avg 0.62;

General: AIRS > ECMWF, stronger seasonal signal

SAL thicknesses (bottom)

Same 300 m detection threshold as non-Saharan locations

Limited dependence to dust (Aqua Deep Blue)

ECMWF: Better captures variance & IQR ranges than AIRS

Likely related to other data assimilated by ECMWF

Hypothesis: Away from stations AIRS likely better (data consistency)
SAL TRAJECTORIES VS AQUA AOD VS TRMM 3B42 PRECIPITATION

- What is shown:
  - Trajectories (24 hrs interval; colors, red most recent)
  - TRMM 24-hr precipitation accumulation (green)
  - Aerosol optical depth > 0.4 (hashed)

- Differences between data sources:
  - Detected SAL or SAL heights

- Trajectory origin points largely uncorrelated with precipitation.
SUMMARY

• Evaluated AIRS SAL detection potential given porous radiosonde network
  • 55 Stations, 13 years of data (2003-2015)
  • Detection of WML (constant Pot. T and mixing ratio), SAL (HYSPLIT)

• WML: All data under-biased, ECMWF performance slightly better (T.S., range of thicknesses)

• SAL detection at each station, 300 m detection threshold
  • Threat score: AIRS slightly higher (0.6 vs 0.58) than ECMWF
  • SAL Thickness: Detection rate over-bias, ECMWF better thickness

• SAL trajectory origin points not well-correlated with precip.

• AIRS results comparable or better than ECMWF at stations
  • AIRS likely better outside radius of radiosonde influence
Thanks for your time and attention!!!
ATMOSPHERIC INFRARED SOUNDER (AIRS) VER. 6

Passive infrared sounder

Resolution: 13.5 km at nadir, 41 km x 21.4 km at scan extremes

Operates in up to 90% cloudiness

Enhanced with Atmospheric Microwave Sounding Unit (AMSU data)

Global temperature and moisture data

Focus: 100-level support product (25 levels ≥ 500 hPa)

Images from AIRS JPL Webpage (http://airs.jpl.nasa.gov/)

AIRS under construction

700-hPa Temperature

Total Precipitable Water
SAHARAN AIR LAYER (SAL) [2]

Dust sources

• Dry convection (Saharan thermals)
• Gravity currents (i.e., storm outflow) -- (Flamant et al. 2007)
• African easterly wave forcing (Karyampudi et al. 1999)
• Mid-latitude, upper level troughs -- Jankowiak and Tanre, 1992)

Impacts to moist convection (Land and ocean)

• Direct: Scatter solar radiation
  • Weaken: cools surface
• Indirect: Act as cloud condensation nuclei
  • Strengthen: Decrease condensate loads aloft