



Does Dry Environmental Air Kill Intensifying Hurricanes?

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Goal: To assess the impact of dry environmental air on hurricane intensification.

Method: Use a computer model to simulate a hurricane under ideal conditions. Then add different configurations of dry air at middle levels and assess impacts on storm intensity and structure.

Results: In environments with weak mean flow, the dry air can slow intensification, but doesn't prevent it.

- Delay in intensification only occurs when dry air starts off close to the center (<150 km)
- No delay occurs when the storm is surrounded by dry air but contains an initial moist core of modest radius
- Contrary to expectations, delay is caused not so much by increased downdrafts of cold air, but by rainband formation that pushes much needed in-cloud heating outward toward larger radius

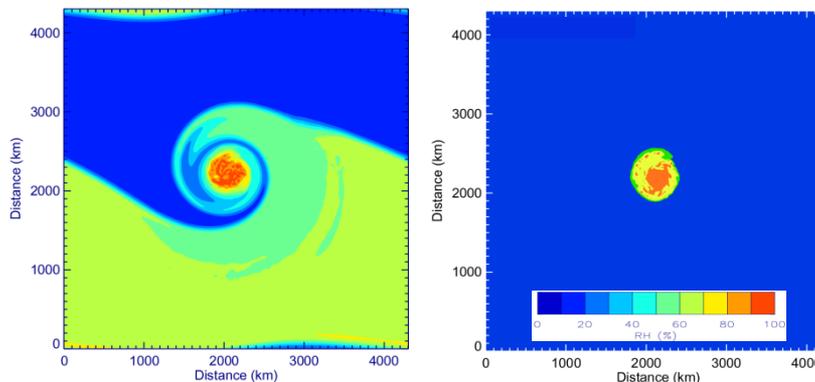


Figure 1: Relative humidity at 3 km altitude after 6 days of simulation time from two experiments. (Left) Dry air is placed north of an east-west line initially located 270 km north of the storm center (DRY270) and gets wrapped around the storm. (Right) Dry air initially surrounds the storm outside a radius of 75 km (DRYALL75). The color scale is shown in panel (b).

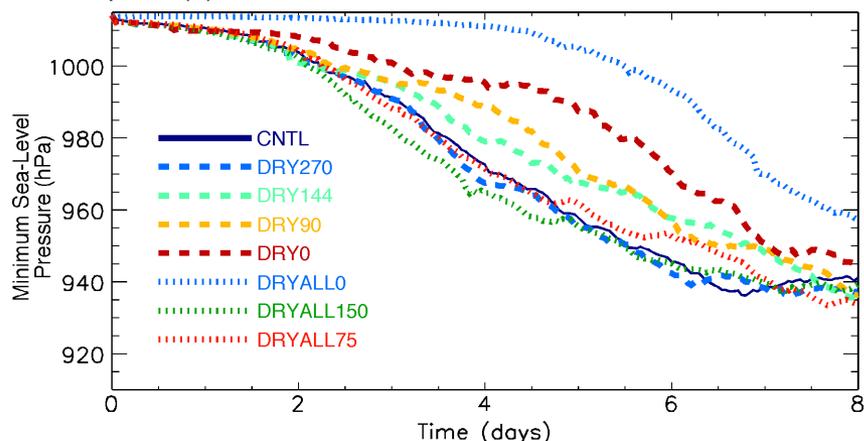


Figure 2: Time series of minimum sea-level pressure for all simulations. The solid line is the control run with no dry air, the dashed lines are the runs with dry air north of a specified distance (km) from the center (DRYXX), and the dotted lines are for runs with dry air throughout the domain except for a small moist envelope within the specified radius (DRYALLXX) of the vortex, with XX indicating distance to the north or radius in km.

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References:

Braun, S. A., J. A. Sippel, and D. S. Nolan, 2012: The impact of dry mid-level air on hurricane intensity in idealized simulations with no mean flow. *Journal of the Atmospheric Sciences*, **69**, 236-257.

Data Sources: All data are from numerical simulations using the National Centers for Atmospheric Research (NCAR) Weather Research and Forecasting (WRF) model. All simulations were conducted on NASA Center for Computational Sciences facilities. The simulations were initialized with a weak initial vortex, 15 m s^{-1} maximum winds at $\sim 4 \text{ km}$ altitude, weakening with height above and down toward the surface. There was no background flow, i.e., no uniform mean flow or vertical wind shear, so in this sense the results are highly idealized. A control simulation was performed using a uniform temperature and humidity profile for the environment representative of typical moist tropical conditions. To assess the impact of the dry air, one set of simulations was performed with dry air (25% relative humidity) between 850-600 hPa at all locations north of a west-to-east boundary located some distance north of the vortex center. This distance varied from 0 to 270 km and the simulations were named DRYXX, where XX indicates the distance in km. Another set of simulations was performed with the same dry air layer, but instead it surrounded the vortex at all azimuths beyond some specified radius from the center. That radius varied from 0 to 75 to 150 km. Air within that radius was identical to the moist tropical air mass. These simulations were named DRYALLXX, where XX indicates the radius beyond which the dry air was located.

Technical Description of Figures:

Figure 1: Plots of relative humidity at 3 km altitude show the relative humidity field at 6 days. Typical of simulations with dry air initially located north of an east-west boundary to the north of the initial vortex center (left), the dry air gets wrapped around the inner, more humid core. On the right, when dry air initially surrounds a small moist core, the dry air remains around this core, but the core expands slightly as convection develops within the hurricane.

Figure 2: Time series of minimum sea-level pressure for all simulations. Lower pressures indicate more intense storms. The lines are explained in the caption. The results show that for initial dry-air-boundary distances (XX) $> 144 \text{ km}$, the dry air produces only a relatively small delay in the intensification of the storm. As the dry-air boundary gets closer or to the center, the delay increases to about 1-2 days, but the storms eventually reach the same final intensity as the control run with no dry air. For the cases in which dry air surrounds the storm (DRYALLXX), when dry air extends to the center (DRYALL0), significant delay occurs, but for modest moist cores of 75 and 150 km radius, the storms intensify as if the dry air is not present at all. Expectations had been that dry air would cause more numbers of and colder downdrafts that might reduce the energy in the boundary layer available to the storms, but we found that this explanation was too simple, particularly since the DRYALL75 and DRYALL150 cases had the coldest boundary layers, but had the same intensities as the control run. A better explanation was found to be related to the formation of intense outer rainbands that would push the azimuthally averaged heating by clouds out to larger radius where they would be less efficient at spinning up the vortex.

Scientific significance: There is frequent debate within the hurricane research and operational communities about the impact of dry air, with some treating it as a major suppressor of hurricane formation and intensification, and others holding that it is very difficult for the dry air to get into the circulation in such a way as to impact intensity. This issue is very difficult to address with approaches other than idealized modeling, and with this study we are trying to provide a context in which observations and real-case simulations can be compared.

Relevance for future science and relationship to Decadal Survey: This work provides a significant context for understanding how dry air impacts developing storms and can provide important information for the analysis of data from the Genesis and Rapid Intensification Processes (GRIP) 2010 field campaign and the 2012-2014 Hurricane and Severe Storm Sentinel (HS3) Earth Venture-1 campaigns.



New AERONET product: Cloud Optical Depth

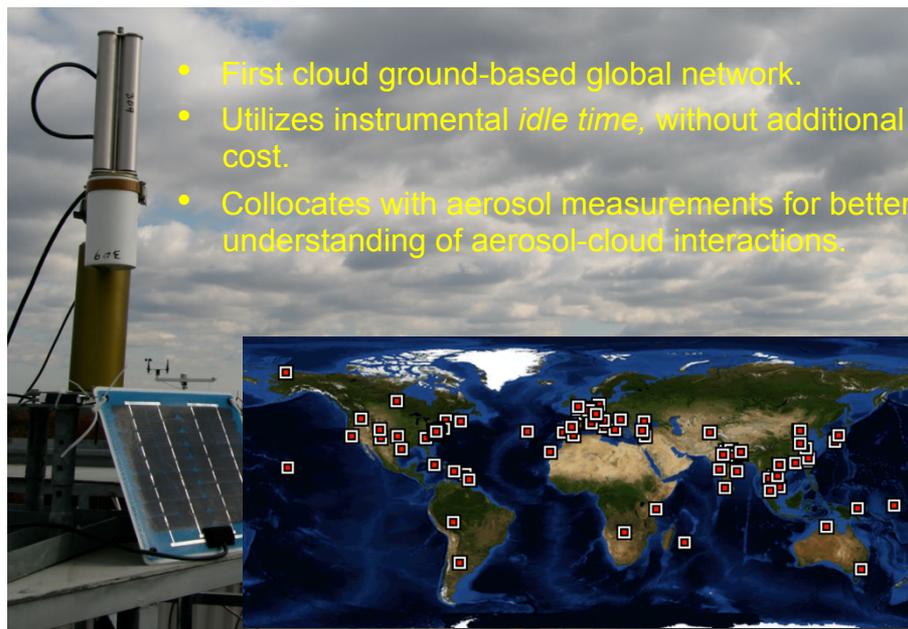
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Clouds are the largest, yet least understood regulators of climate. Accurate measurements of key cloud-climate variables like cloud optical depth are critical to predicting climate change.

Figure 1 shows the operational cloud mode sites which are the first ground-based global network for cloud observations. Having collocated aerosol and cloud measurements is an important step in understanding the links between these two components of our climate system.

Figure 2 reveals that AERONET cloud-mode optical depth retrievals are well consistent with those retrieved from MODIS. As a result of monitoring clouds at many AERONET sites, the retrieved cloud optical depth will be used not only for validation of satellite retrieved cloud properties, but also for studying local climatology and the diurnal cycle not available from satellites. Monitoring clouds under different climatological conditions provides a reliable database for comparison with cloud models output in support of cloud system modeling.

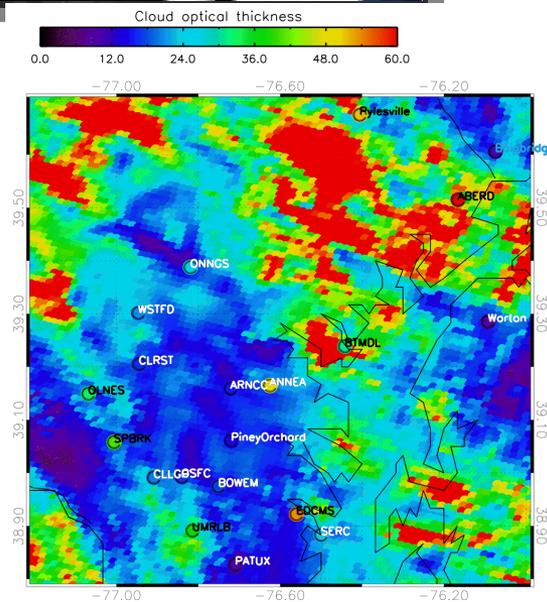
The Aerosol Robotic Network (AERONET) is a ground-based network designed to measure microphysical and optical properties of aerosols. In addition to measuring aerosols, we proposed a method for monitoring cloud optical properties by using the Cimel sunphotometer's "idle time", which is inappropriate for aerosol study, by taking measurements of zenith radiance at 0.44 and 0.87 μm . Cimel zenith radiance measurements combined with surface reflectance properties are used to determine the overlying cloud properties. Working in a new "cloud" mode every 15 min, if the Sun is blocked by clouds, the Cimel radiometer points straight up and takes 10 measurements with a 9 sec. time interval. Surface reflectance properties are updated twice a month using standard Terra and Aqua atmospherically-corrected surface reflectance products. The latest AERONET product, 'Cloud Optical Depth' is available on the AERONET website (<http://aeronet.gsfc.nasa.gov>).



- First cloud ground-based global network.
- Utilizes instrumental *idle time*, without additional cost.
- Collocates with aerosol measurements for better understanding of aerosol-cloud interactions.

Figure 1: The posture of Cimel radiometer in cloud mode. The map shows the distribution of the 271 AERONET stations used to retrieve cloud optical depth.

Figure 2: A snapshot of regional cloud optical depth from AERONET and MODIS. The underlying map is the COD measurements of MODIS/Terra on 16:20 GMT, Aug. 03, 2011. Based on a 10 min. time window centered at the MODIS overpass time, 20 AERONET sites provided COD measurements indicated by circle.





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Chiu, J.C., C.-H. Huang, A. Marshak, I. Slutsker, D. M. Giles, B.N. Holben, Y. Knyazikhin, and W.J. Wiscombe, 2010: Cloud optical depth retrievals from the Aerosol Robotic Network (AERONET). *J. Geophys. Res.*, *115*, D14202, doi:10.1029/2009JD013121.

Chiu, J.C., A. Marshak, Y. Knyazikhin, W.J. Wiscombe, H.W. Barker, J.C. Barnard, and Y. Luo, 2006: Remote sensing of cloud properties using ground-based measurements of zenith radiance. *J. Geophys. Res.*, *111*, D16201, doi:10.1029/2005JD006843.

Marshak, A., Y. Knyazikhin, K. Evans, and W. Wiscombe, 2004: The "RED versus NIR" plane to retrieve broken-cloud optical depth from ground-based measurements. *J. Atmos. Sci.*, *61*, 1911-1925.

Data Sources: AERONET cloud mode observations (http://aeronet.gsfc.nasa.gov/cgi-bin/type_piece_of_map_cloud), and MODIS Level 2 cloud products.

Technical Description of Figures:

Figure 1: A new AERONET strategy, called "cloud-mode", takes advantage of instrumental idle time to measure zenith radiance and retrieve cloud optical properties. AERONET cloud optical depths retrieved from 271 AERONET stations are available from Nov. 2004 till now.

Figure 2: A snapshot of ground measurements overlapped with the satellite cloud optical depth (COD) retrievals during the AERONET DRAGON field campaign in DC area, 2011. The underlying map is the COD measurements of MODIS/Terra on 16:20 GMT, Aug. 03, 2011. Based on a 10 min. time window centered at the MODIS overpass time, 20 AERONET sites provided COD measurements indicated by circle. The colors of site names indicate different cloud phases, black is for liquid, white is for ice and blue is unknown.

Scientific significance:

Cloud optical depth is the most important of all cloud optical properties, and vital for any cloud-radiation parameterization. Its impact on radiative fluxes and therefore climate is matched only by cloud fraction. Satellites retrieve cloud optical depth but satellite methods alone cannot solve the optical depth problem. AERONET cloud mode is the first ground-based global network for clouds. The retrieved cloud optical depth will be used not only for validation of satellite retrieved cloud properties but also for studying local climatology and the diurnal cycle not available from satellites.

Relevance for future science and relationship to Decadal Survey: Clouds are the largest yet least understood regulators of climate. Accurate measurements of key cloud-climate variables like cloud optical depth is critical to predicting climate change and is an important part of current (Terra, Aqua, NPP) and future NASA missions such as PACE and ACE.



Aura Ozone Monitoring Instrument (OMI) sees BrO enhancements over the North Pole

Why is BrO important in the Arctic?

•BrO plays an important role in tropospheric ozone chemistry and the resulting oxidation capacity of the polar boundary layer

•Bromine radicals catalytically destroy ozone, leading to nearly complete removal near the surface that is termed an ozone (O₃) depletion event (ODE).

•Br and BrO are thought to oxidize elemental mercury to more reactive (toxic) gaseous mercury that deposits to the polar ecosystem

OMI, with its wide swath, is the only instrument that can detect BrO at the pole on every orbit. Here, stratospheric BrO has been carefully separated from the total column (using a chemical and dynamical model) to produce estimates of the tropospheric BrO column. Validation was accomplished with aircraft *in situ* measurements during the NASA ARCTAS field campaign, showing that bromine chemical activation takes place at the Arctic near the surface.

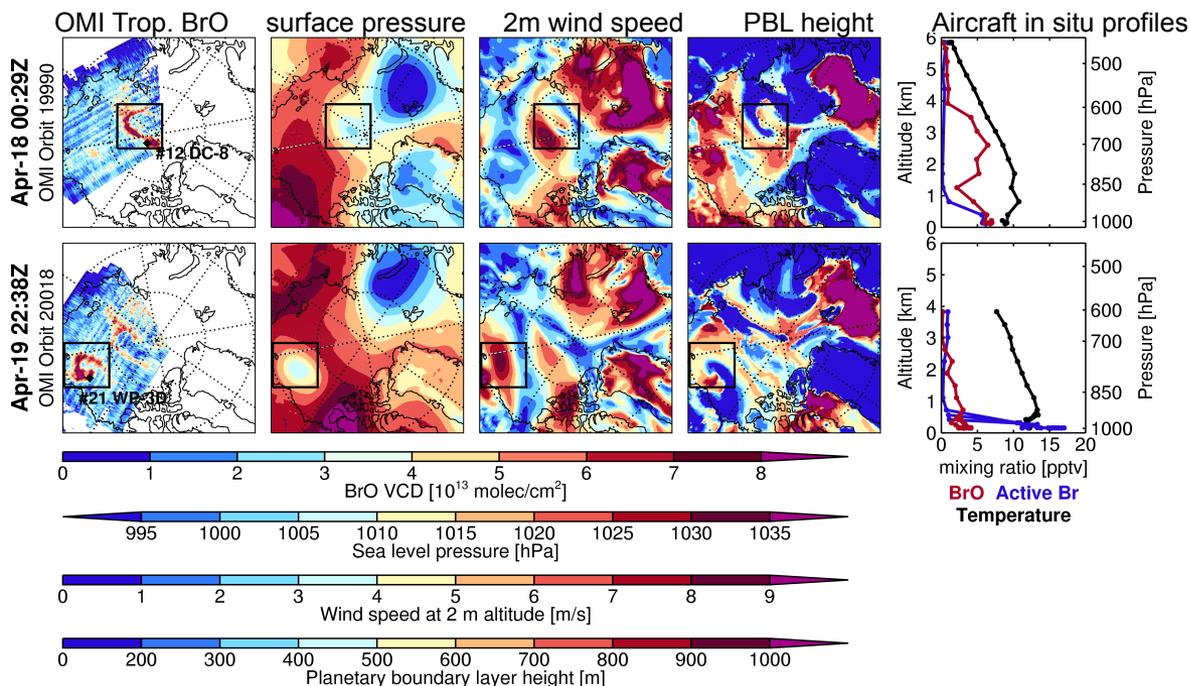


Figure 1: Two flights through areas of enhanced tropospheric BrO (boxed regions) near the North pole. 1st column: derived tropospheric BrO column from OMI. 2nd column: sea level pressure from GMAO reanalysis. 3rd column: wind speed near surface from GMAO. 4th column: planetary boundary layer (PBL) height. 5th column: temperature and bromine constituent profiles from in situ aircraft sensors. This analysis shows that BrO activation occurs in low pressure systems with high winds (owing presumably to blowing snow) and/or when the planetary boundary layer is thick and there is sufficient ozone to maintain catalytic chemical reactions that produce BrO.

Sungyeon Choi et al., ACPD, 2011. Georgia Institute of Technology, (PhD candidate working also at NASA/GSFC)



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References: Choi et al. 2011, Analysis of satellite-derived Arctic tropospheric BrO columns in conjunction with aircraft measurements during ARCTAS and ARCPAC, *Atmos. Chem. Phys. Disc.*, 11, 26173-26243, doi:10.5194/acpd-11-26173-2011, accepted pending revisions.

Data Sources: NASA Aura Ozone Monitoring Instrument (OMI), Chemical Ionization Mass Spectrometer (CIMS) BrO measurements from DC-8 and WP-3D aircraft, EUMETSAT Global Ozone Monitoring Instrument 2 (GOME-2), NASA Goddard Modeling and Assimilation Office (GMAO) MERRA reanalysis

Technical Description of Figure: To derive the tropospheric column of BrO, the stratospheric column is first estimated using a chemical and dynamical model developed at the University of Maryland by coauthors Ross Salawitch and Tim Canty. The stratospheric column is subtracted from the total column that is produced by coauthors Kelly Chance and Thomas Kurosu at the Harvard Smithsonian Astronomical Observatory (SAO). The residual tropospheric column must be carefully computed by assuming a profile shape. Here, we used a composite profile derived from ARCTAS field campaign measurements.

Scientific significance: Before the ARCTAS and ARCPAC field campaigns, ground- and satellite-based data, primarily from remote sensing, indicated numerous areas with large enhancements of BrO, thought to be occurring near the surface where it is hypothesized that bromine is released from blowing snow. The enhancements were linked to events of severe ozone depletion also near the surface. One of the objectives of the ARCTAS campaign was to fly into these regions and analyze the chemical composition of the air. When the aircraft were guided into the BrO “hot-spot” areas using satellite data, researchers were very surprised to see neither BrO enhancements nor ozone depletions. Salawitch et al. (GRL, 2010) showed that much of the BrO seen by satellites in these hot spot areas, was in fact due to compressed BrO in the stratosphere. This study takes the next step in interpretation of data from the ARCTAS campaign.

This is the first study to quantitatively evaluate satellite-based estimates of tropospheric BrO in the Arctic with aircraft *in situ* measurements. We show for the first time a rapid activation of bromine chemistry at high temporal resolution, made possible by wide-swath OMI observations. Two flights crossed regions of high tropospheric BrO and both were validated by the aircraft sensors. The study therefore gives further weight to the hypothesis that there is a tropospheric source of bromine. By using high resolution meteorological from the NASA GMAO, we show that the source is related to high winds (blowing snow) associated with low pressure systems and/or a high planetary boundary layer where the catalytic bromine-ozone chemistry can be maintained. The study also emphasizes the importance of having an accurate estimate of the stratospheric contribution to the total BrO column. We also showed that tropospheric BrO can only be observed in the Arctic only under certain conditions (over bright surfaces – primarily ice), when thick clouds are not present, and not at very high solar zenith angles.

Relevance for future science: This study shows that careful analysis of OMI BrO and similar satellite data is needed to properly interpret the basic measurement which is the number of molecules observed along the sunlight (slant) path. Similar analysis will need to be applied to data from future satellites. Future satellites that will be able to measure BrO include the EUMETSAT GOME-2 series and ESA TROPOMI. The only NASA decadal survey mission that may measure Arctic BrO is the tier 3 GACM.