Assimilation of Doppler Wind Lidar (DWL) Wind Profiles for Improved Severe Weather Forecasts

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Background

Winds = Dynamics of Atmosphere
Winds = Primary driver of evolution of atmosphere

Wind data available in weather/climate analysis

- Radiosonde
- Satellite-derived atmospheric motion vectors (AMVs)
- Radar radial velocity
- Ocean surface winds from the satellites (e.g., CYGNSS, ASCAT)
- Surface or local measurements from some special networks and field campaigns

There is a lack of wind profile measurements

Significant efforts and development have been devoted for potential space-based wind mission by US scientists.

Baker et al. (2014) BAMS
In this talk

- Summarizes studies we have been done to explore the options and influences of wind profile measurements on numerical prediction of high-impact weather systems
  - Data assimilation and observing system simulation experiments (OSSEs) using ground, airborne, and satellite-based Doppler Wind Lidar (DWL) platforms for more than a decade

- Results from recent data impact study with DAWN wind profiles during NASA Convective Processes Experiment (CPEX)

- Concluding remarks and ongoing work
Airborne DWL profiles, collected during TPARC/TCS-08 from ONR P-3

Case

Typhoon Nuri over the Western Pacific

- Wind profiles with 50 m vertical and 1 km horizontal resolution

Time period of data

2330UTC 16 August to 0200UTC 17 August 2008 (about 3-h)

Zhaoxia Pu and Lei Zhang, Department of Atmospheric Sciences, University of Utah
G. David Emmitt, Simpson Weather Associates, Inc.

Model: Mesoscale community Weather Research and Forecasting (WRF) model
Data: Doppler wind Lidar (DWL) profiles during T-PARC for the period of 0000UTC –0200 UTC 17 August 2008
Forecast Period: 48-h forecast from 0000UTC 17 August 2008 to 0000UTC 19 August 2008
Control: without DWL data assimilated into the WRF model.
Data Assimilation: With DWL data assimilated into the WRF model

Data impact: Control vs. Data assimilation
Ground-based Lidar Winds (B. Gentry and B. Demoz, NASA/GSFC)

GLOW (Goddard Lidar Observatory for Winds) Lidar Wind Observations

International H₂ O Program (IHOP) field program: May and June 2002

Wind profile Resolution: 10 minutes; 100m below 3km and 200m above 3km of the height over 240 h of data in 35 days

Observations at Homestead site, OK during 12-13 June 2002
June 12 2002 Convection Case

Composite radar reflectivity observations

2100 UTC
12 June
2002

0100 UTC
13 June
2002

2300 UTC
12 June
2002

0300 UTC
13 June
2002
CTRL (Left) Vs. 4DVAR (right): Simulated Radar Reflectivity

2100 UTC 12 June

2300 UTC 12 June

0100 UTC 13 June

0300 UTC 13 June
Quantitative Precipitation Forecasting Scores

Ratio of equitable threat scores (ETS)
4DVAR vs. CTRL

Zhang and Pu 2011, MWR
Regional OSSEs

Pu et al. 2017
Exp. I: First Snapshots of the Satellite-based DWL Observations

3rd generation DWL configure (Dr. G. D. Emmitt)

Case 1: No cloud impact

Case 2: With cloud impact
Impact of Satellite-based DWL Observations

A regional OSSE study

Zhang and Pu (2010)


Impacts from assimilation of “DWL” profiles

(48-h FCST)
Data samples in various resolutions (Hurricane “Bill” 2009)

# 1
(60km)

# 2
(120km)

# 3
(180km)

Vertical resolution: 250m below 2km; 1 km above 2km
Accumulated 3-h rainfall forecasts at 1200 UTC 19 Aug.

(a) Truth  
(b) CTRL  
(c) Sam 1  
(d) Sam 2  
(e) Sam 3

Pu et al. (2017)
NASA CPEX  June 2017
Doppler Aerosol WiNd (DAWN) Lidar
Satellite infrared brightness temperature & ERA5 900hPa height

Case 1
June 15-16, 2017

Case 2
June 20-21, 2017
TS Cindy

Cui et al. (2019)
WRF model domains & DAWN data sample

June 15

June 20
Data Assimilation methods

NCEP GSI-Based 3D Ensemble-Variational Hybrid Data Assimilation

\[ J(x) = \frac{1}{2} (x - x^b)^T (\beta_1 B_1 + \beta_2 B_2)^{-1} (x - x^b) + \frac{1}{2} (y^0 - H(x))^T R^{-1} (y^0 - H(x)) \]

\( B_1 \) : Static, pre-generated matrix using NMC method
\( B_2 \) : A flow-depend matrix derived from ensemble forecasts

Weighting factors: \( \beta_1 \) and \( \beta_2 \)

NCEP GSI 3D Variational Data Assimilation (3DVAR)

When \( \beta_2 = 0 \)
Area Averaged Divergence

Compare with radiosonde obs.

Cui et al. (2019)

Case 1, 12 UTC 16 June 2017
Rainfall rates and QPFs

Case 1

Cui et al. (2019)
Rainfall rates and QPFs

Case 2

Cui et al. (2019)
Concluding remarks and ongoing work

- Space-based 3-D wind profiling measurements are essential for improving high-impact severe weather events.
- Both ground-based and airborne Doppler wind lidar measurements are valuable for high-impact weather forecasting. They should be actively used in the future field campaigns and operational missions.

- Assimilation of DAWN wind profiles results in improved numerical simulations of tropical convection during NASA CPEX.

- Ongoing studies emphasize 1) NOAA/HJRD/P3 lidar winds for hurricanes and 2) Aeolus wind data.
Thank you very much for your attention!
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