Assimilation of GPS Data for Short-Range Precipitation Forecast

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Purpose: Discuss the use of GPS networks for meteorology (and earthquake research)
• SW is the integrated water vapor along single GPS ray paths
• PWV is “the average of all SW observations in a cone scaled to zenith”
• Simultaneous observations along 8-12 GPS ray paths
• GPS and WVR sensed SW and PWV agree to ~1.5 mm rms
Outline

• Beijing GPS Analysis
  • Assimilation of PWV leads to improved forecast

• US Studies
  • PWV during Hurricane Katrina
  • BAMEX (3DVAR WRF Assimilation)
  • IHOP (4DVAR MM5 Assimilation of Slant Water Vapor)

• Japan’s GEONET
  • GPS Meteorology
  • Typhoon 20

• Observations from the Ocean

• Geodetic/Seismic Application of GEONET

• Summary
Beijing Flood Case
一、灾情

20040710北京遭遇突发性强雷雨袭击。其范围小、突发性强、发展快、常规气象要素难以捕捉。
Model Domain and Terrain

Model Configuration

- Two domain, run in two-nested mode
- Domain 1: 12 km; domain 2: 4 km
- Physics used in domain 1:
  » KF CU, YSU PBL, 5-layer soil model (not LSM), RRTM lw, Dudhia sw
- Physics used in domain 2:
  » Same as in domain 1, except no KF
  » Two different microphysics options: Lin et al. (1983) and WSM-6
Data Used

- GFS final analysis at 1 degree resolution
- Radiosonde, surface and AWS observations obtained from BMB
- GPS PW from Fang Shan obtained from BMB
The GPS network in FangShan Beijing area of China

- 8 GPS Stations with mean distance less than 10km
- A Vaisala AWS(P,T,RH) built on each GPS station
- YSDD->54511 ~ 30 km
- YCSS->RAIN_GAUGE ~ 5km

54511(Brown Square): The Radiosonde Station
RAIN_GAUGE(Green Diamond): The FangShan AWS
Black triangle: Four Single Frequency GPS Stations of BMB
Black circle: Four Dual Frequency GPS Stations of BMB

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Experiments

- Control: or experiment A
  - GFS data only, used for both IC and BC
- 3DVAR 1: or experiment B
  - GFS + radiosonde, sfc + AWS
- 3DVAR 2: or experiment C
  - GFS + radiosonde, sfc + AWS + GPS PW

All experiments start at 1200 UTC 7/9/04 and run for 36 hours
6-h accumulated rainfall 06-12 UTC 10 July 2004

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GFS

OBS

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Difference in PW due to Assimilation Of GPS PW

12 UTC 9 July
6-h accumulated rainfall 06-12 UTC 10 July 2004

GFS

BMB+PW

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BMB+PW
4-km WRF
Radar ref.
Wind at 1km

WSM-6
microphysics
Beijing Case Preliminary Conclusions

- WRF 4-km model initialized with the NCEP GFS analysis did not produce any precipitation over Beijing. GFS is quite good on the larger scale, but it fails to capture the mesoscale details.

- WRF 3D-Var assimilation of local data set makes a big difference in the stability of the local convective environment.

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- Simulation of convective evolution is sensitive to quality of mesoscale analysis and precipitation microphysics (WSM-6 microphysics resulted in better forecast than Lin microphysics)
US Examples
Katrina Time Series

GPS PW (red)
Pressure (blue)
MM5 4DVAR of GPS SWD - So-Young Ha

GPS SWV

Radar+

12-Jun-2002, 18:00:00  Zebra projection: goes_1km albedo plot: radar_composite DZ plot: p3 dewpoint temperature track with wind vectors. dc8 track with wind vectors.

REAL-TIME DATA, NOT CHECKED FOR QUALITY

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Japan's GEONET
Ground-based GPS Network in Japan

- 1223 sites with relatively even spacing of 17 km (only on the islands)
- Most of the antenna was replaced to choke-ring antenna in 2003
- Improvement of coordinate RMS repeatabilities (=> improve ZTD estimates)

Short-term repeatabilities in radial component of the coordinate in 2002 (left) and 2004 (right).
WRF Forecast with GPS PWV in Japan

1 hr integrated rainfall (mm).

8~9 hr after IC of forecast (control), 2~3 hr after free forecast (cycling)

- GPS PWV cycling data assimilation shows positive impact on rainfall
- Several hours forecast is beneficial in the Japanese Islands

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Rapid analysis of GEONET ZTD

Typhoon 14th hit western Japan

It is important to install pressure gauges at GPS stations because a decrease in pressure can cancel the increase in PWV in the GPS delay signal.
GPS Meteorology at Sea
PWV from Cruise Ship

Explorer of the Seas August 2003 PWV From GPS/WVR/RAD

GPS/WVR Agreement: mean 1.2mm std 2.8mm

Raob
MWVR
GPS PWV

PWV [cm]

3.5 4.5 5.5 6.5

GPS PWV [cm]

Day of Year 2003

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Gulf Buoy Network
GPS Seismology in Japan
Summary

- Case studies in the US, China, Japan have show positive impact of GPS water vapor in forecasting
  - Results are sensitive to cloud microphysics, surface processes, radiation, time integration schemes, finite differencing, …etc
  - Results over US show positive impact out to 18 hours
  - Slant water has shown better impact than PW (only short term)
  - Forecast impact in Japan is generally short-term (lack of data over oceans)
- Taiwan GPS network can potentially be used for
  - Now-casting using real-time PWV time series
  - Short term precipitation forecast possible
- Required development
  - Network must be real-time
  - Pressure data must be available because sharp topography + typhoon pressure drop will make assimilation of tropospheric delay difficult
  - No conflict between geodetic/seismic and meteorological applications
3. Forecasts of Rainfall
Forecast: WRF/3DVAR System

Minimization of cost function: \( J(x) \)
\[
J(x) = J^b + J^o = \frac{1}{2} (x - x^o)^T B^{-1} (x - x^o) + \frac{1}{2} (y - y^o)^T (E + F)^{-1} (y - y^o)
\]
Observation operator
\[
y = H(x)
\]

- Background error statistics come from NMC methods in global model run
- Tuning of scale length is required for each domain
  Control variable of specific humidity:
  0.35 for the U.S. domain, 0.09 for the Japanese domain

Covariance matrices
B: Background error
E: Observation error
F: Representativity
H: Observation operator
3. Forecasts of Rainfall
Cycling 3DVAR and WRF Forecast

Strategy of Model Run

00Z
T=00h  T=06h  T=12h  T=18h  T=00h  T=06h  T=12h

18h forecast
18h forecast
18h forecast
13h forecast
Repetition

Initialization (IC)
Data ingestion

Same parameter setting with real-time WRF forecast
(see http://www.mmm.ucar.edu/wrf/REAL_TIME/real_time.html)
- Lin's microphysics, no cumulus parameterization
Data assimilation

- SWD (32 sites, every 10 min)
- PW (32 sites, every 30 min)
- Wind_profiler (12 sites, hourly mean)
- Surface dewpoint temperature (255 sites, every 5 min)
SWD assimilation is superior to PW assimilation in improving the retrieval of horizontal wind fields.
• PW rms error verified against 32 GPS sites
• The rms errors are increased very quickly after 7-hr forecast time.
• The value in () is a time-averaged rms error for 7 forecast hours.

=> (SWD+Wprf) assimilation has the smallest rms error.
• The assimilation of SWD has largest impact on the moisture retrieval.
BMB+PW
4-km WRF
Radar ref.
Wind at 1km

Lin et al.
microphysics
JMA rainfall nowcasting

- up to 60 minute rainfall forecast every 10 minutes
- 1km grid

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Summary

- GEONET PWV Data Assimilation
  - Development and validation (OSE, OSSE) of ZTD, ZWD data assimilation

- Rapid GEONET data analysis
  - GEONET ZTD using IGU products with 3 hr latency

- 10 year GEONET Analysis for Meteorology/Climatology
  - 5 minute products of ZTD (PWV), gradient, slant delay, and coordinate

- Nowcasting with real-time GPS analysis
  - Get maximum benefit of the dense GPS network in small nations

- Buoy GPS observation would be beneficial for island nations
  - Hope for Hurricane / typhoon simulation (OSSE)

- Collaboration with other nations
  - Data exchange, observation in the ocean