Supporting NOAA's Commercial Weather Data Project

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What is the goal?

- The National Oceanic and Atmospheric Administration (NOAA) is conducting a demonstration project to investigate the viability of assimilating commercially-provided Global Navigation Satellite System (GNSS) Radio Occultation (RO) data and products into the meteorological models and determine impact on weather forecasts.
- Evaluate quality of commercially-provided GNSS RO data and its impact on the skill of the NOAA’s weather forecast models by a neutral party - DTC.
Who is working on this?

- UCAR/COSMIC Program Office
  - Process raw commercially-provided RO data and provide basic data quality assessments
- NCAR Research Application Laboratory (RAL)
  - Provide observation error estimates
  - Conduct data impact study, using NOAA’s Rapid Refresh (RAP) regional forecast system
- Joint Center for Satellite Data Assimilation (JCSDA)
  - Conduct data impact study, focused on global applications
Radio Occultation concept

- Occultation occurs when GNSS satellite rises or sets across the limb wrt to LEO (Low Earth Orbit) satellite.
- Ray passing through atmosphere is refracted due to vertical gradient of refractivity (density).
- During an occultation (~3 min) the ray path slices through the atmosphere.

Raw measurement: change of delay (phase) of signal path between GNSS and LEO during occultation (includes the effect of the neutral atmosphere and the ionosphere).

(Courtesy of Lidia Cucurull)
Choice of ‘observations’

- Raw measurements of phase of the two signals (L1 and L2): $s_1$, $s_2$,
- Bending angles (change in the ray path direction accumulated along the ray path) of L1 and L2: $\alpha_1$, $\alpha_2$,
- (neutral) bending angle: $\alpha$,
- Refractivity, $N = 10^6 (n-1)$,
- Atmospheric products: $T$, $Pw$, $P$,
- Hydrostatic equilibrium, eq of state, *apriori* information,
- Ionospheric correction,
- Clock correction, orbit determination, geometric delay,
- Abel transform.

(Courtesy of Lidia Cucurull)
Observational error assessment – Comparison w/ co-located radiosondes

- **Data**
  - RO refractivity data from the COSMIC CDAAC data archive
  - KOMPSat-5 (Korea Multi-Purpose Satellite-5)
  - COSMIC (Constellation Observing System for Meteorology, Ionosphere, and Climate)
  - Radiosonde data from NCAR Research Data Archive, quality controlled
  - Time period: 1 June 2016 through 1 June 2017

- **Method**
  - Calculate refractivity from radiosonde data
    
    $$ REFrs = 77.6 \times \frac{P_d}{T_k} + 373000 \times \frac{P_w}{(T_k \times T_k)} + 70.4 \times \frac{P_w}{T_k} $$
  - Match radiosonde - RO pairs: 200 km horizontal distance, +/- 2 hours, +/- 40 m height difference
Scatter plots of radiosonde refractivity vs KOMPSat-5

Box plots of KOMPSat-5 and COSMIC refractivity

KOMPSat-5: 85,605 total observations; COSMIC: 130,467 total observations
Mean percent difference

\[ pDiff = 100 \times \frac{\text{radiosonde refractivity} - \text{RO refractivity}}{\text{radiosonde refractivity}} \]
Observational error assessment - Comparison with global forecasts

Data

- RO data from the COSMIC CDAAC data archive
- KOMPSat-5 (Korea Multi-Purpose Satellite-5)
- COSMIC (Constellation Observing System for Meteorology, Ionosphere, and Climate)
- Both refractivity and bending angle data
- 3-h global forecasts, provided by NCEP’s Global Forecast System (GFS), on sigma levels, as well as the surface boundary conditions, out to 27-h lead time from NOAA’s HPSS data archive
- Time period: 1 August – 31 October 2016
Observational error assessment – Comparison with global forecasts

- Method
  - Following the RO error estimation effort described by Kuo et al. (2004). The difference between an observing system and a short term forecast, referred as apparent errors ($\sigma_a^2$), includes the observation errors ($\sigma_o^2$) and forecast errors ($\sigma_b^2$).
  - Assuming the observation errors are uncorrelated with the model errors, estimate the observation error variances ($\sigma_o^2$) by subtracting the model forecast error variances ($\sigma_b^2$) from the apparent error variances ($\sigma_a^2$)
    $$\sigma_o^2 = \sigma_a^2 - \sigma_b^2$$
  - Operational GSI (Gridpoint Statistical Interpolation) data assimilation system used to compute simulated RO observations (either bending angle or refractivity) and calculating both the apparent errors and model errors
    - Apparent error variances ($\sigma_a^2$)
      - Variance of the difference between the RO observations and 6-hour GFS forecasts
    - Model forecast error variances ($\sigma_b^2$)
      - National Meteorological Center (NMC) method, introduced by Parrish and Derber (1992), using the differences between 12-h and 24-h GFS forecasts
Fractional forecast errors – KOMPSat-5

**Fractional forecast error:**
\[
\frac{\text{forecast error}}{\text{mean observation}}
\]
Fractional refractivity errors

Fractional refractivity error: \[
\frac{\text{refractivity error}}{\text{mean observation}}
\]
Fractional bending angle errors

![Graphs showing bending angle errors for KOMPSat-5 and COSMIC.](image)

Fractional bending angle error: $\frac{\text{bending angle error}}{\text{mean observation}}$
KOMPSat-5 fractional refractivity observation errors (for all latitude bands)

0.5-day: ~ 160-390 observations

1 day: ~ 200-600 observations

3 months: ~ 20,000-63,000 observations
Summary

- Tools developed will be used to investigate the viability of assimilating commercially-provided GNSS RO data and products into the meteorological models.

- Overall the KOMPSat-5 and COSMIC refractivity data matches very well to the calculated radiosonde refractivity.

- Estimated observation errors based on GFS forecasts show very similar features between KOMPSat-5 and COSMIC, with bigger fractional errors in the lower troposphere and in the tropics, and is consistent over time.
On-going work – KOMPSat-5 data impacts on forecast skills

- End-to-end forecast system that closely emulates NOAA’s continental-scale hourly-updated assimilation/modeling system referred to as the Rapid Refresh or RAP
- Testing period: 1-31 August 2016
- Two configurations to assess the sensitivity of the forecast skill to the assimilation of KOMPSat-5 GNSS RO data:
  - With KOMPSat-5 RO data assimilated, in addition to other observations
  - Without KOMPSat-5 RO data assimilated
Thank you!

Questions?