Present status and future directions of GNSS assimilation at NRL

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Introduction

Summary of Operational Status

- **Operational Procedure**
  - Forward Operator (ROPP)
  - Observation error specification
  - Tangent point drift considerations

- **Sensors assimilated**
  - List of sensors and any caveats

- **Impact assessment**
  - Monitoring
  - FSOI (Forecast Sensitivity to Observation Impact)
    - *Shown to the right (GPS highlighted in red)*

**New Observations**

- KOMPSAT-5, GRAS MetOp-C, PAZ,
- SPIRE, GeoOptics
- CYGNSS (CYclone Global Navigation Satellite System)
- GNSS-Reflectometry growth will be rapid

**Future Directions**

- Improved observation error (based on humidity)
- 2D Operator

[Image of NAVGEM Observation Sensitivity chart]

https://www.nrlmry.navy.mil/metoc/ar_monitor/
Summary of Operational Status

• Details of GNSS-RO assimilation
  − Assimilation of bending angle
  − 60km cap
  − Occultation points treated as independent tangent points

• Quality control checks
  − Check on the vertical bending angle gradient

• Observation error specification
  − Based on observed RMS statistics from assimilation system
    • Surface maximum 25% at Equator, 16.5% at pole
    • Decline throughout tropopause to 1.5%
    • 1.5% bulk of stratosphere
    • Use max of 0.6 μrad –or– 1.5% of observation
Operational Status: Sensor Availability

**Sensors recognized in Operations**
- C/NOFS
  - CORISS (x)
- COSMIC
  - FM1
  - FM2 (x)
  - FM3 (x)
  - FM4 (x)
  - FM5 (x)
  - FM6
- GRAS
  - MetOp-A
  - MetOp-B
  - MetOp-C
- GFZ
  - TerraSAR-X
  - TanDEM-X
  - GRACE-A (x)
  - GRACE-B (x)
- KOMPSAT5
  - AOPOD

**“Plumbed” but not Operational**
- SPIRE
- PAZ
- ROHPP

**Expected in near Future**
- COSMIC-2
- GRACE-FO
Summary of Operational Status

2014 NAVGEM v1.2
- T359L50
- EDMF

2015 NAVGEM v1.3
- T425L60
- $\Theta_v$ dynamics

2017 NAVGEM v1.4.1
- Hybrid DA
- CrIS
- HypsIR WV

2019 NAVGEM v1.4.3
- Correlated Ob Error

Evolution shows gradual improvement near model upper boundary

Upper plots: mean[(O-B)/B]  Lower Plots: stdv[(O-B)/B]
Summary of Operational Status

Forecast Sensitivity to Observation Impact (FSOI)
- Consistent impact
- Metric weighted towards troposphere
  - Norm is a total energy norm
  - Combines temperature, humidity, divergence and vorticity

GNSS-RO network
- Most sensors used up to 60km
- Attempt to use in troposphere large dropoff due to conservative quality control
**CYclone Global Navigation Satellite System**

- 8 micro-sats launched Dec. 16, 2017 in LEO
- High frequency temporal sampling of inner TC structure and low spatial observation revisit time (mean ~7 hrs)
- Unprecedented spatial coverage and observation count in any weather condition due to use of microwave L-band
- Delay Mapping Receive (DMR) processes direct and reflected GPS signals to produce Delay Doppler Maps (DDMs), a representation of sea surface roughness due to winds
- **Forward Model needed!**
Soil Moisture Signal
(Courtesy Mohammad Al-Khaldi, Ohio State)

- Difference monthly mean CYGNSS signal to noise ratio over land (no soil moisture retrieval algorithm... yet) – 1 month change in SNR
- Compare with SMAP 1-month difference in soil moisture
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Land Surface Inundation
(Clara Chew, Talk 4.4, Tues 8 Jan, 9:15 AM)

- CYGNSS signal sensitive to surface water – examine Amazon

https://data.cosmic.ucar.edu/gnss-r/soilMoisture/cygnss/level3/
Future Directions

Plans and Investigations

PAZ
- 13Aug2019 available from NOAA, but not yet on GTS

COSMIC-2
- Ready to evaluate and use the data upon release

Observation Error
- Error estimate based on atmospheric humidity profile
- Additional investigations into error modeling in lower troposphere could bring more improvements

2D Observation Operator
- Begin testing 2-dimensional bending angle operator
- Plan is to treat occultation in segments to alleviate the condition of crossing covariance volumes