Observing system science at GMAO in support of low-Earth orbiting micro-satellite constellations

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7th International WMO Symposium on Data Assimilation  Florianópolis, Brazil, 11 – 15 September 2017
Micro-satellite constellations

A system-of-systems approach to enhance remote sensing for weather and climate applications

- high-resolution configurable coverage scenarios
- rapid refresh rates
- low-cost fabrication and access to launch

**MISTiC™ Winds**

Midwave Infrared Sounding of Temperature and humidity in a Constellation for Winds

**TROPICS**

Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats
NASA/GMAO involvement

- NASA-supported missions in various phases of design and development
  - MW and hyperspectral IR sensors deployed in multiple orbital configurations
  - seek high-quality vertical profiles of temperature, humidity, precipitation and winds

- GMAO is conducting observing system science underlying various aspects of the development of these missions
  - operational-quality data assimilation system
  - infrastructure for OSE, OSSE, and FSOI
  - mandate to support mission development

- This talk focused mostly on MISTiC™ Winds
  - mission concept
  - OSSE development and initial results
GMAO OSSE system

Talk by Ron Errico, Thursday 4:20pm

- Full observing system circa 2016 from 7-km GEOS Nature Run
- Uncorrelated random errors added to all synthetic obs; correlated random errors added to some obs types
- Synthetic observations and their errors are adjusted to increase realism of OSSE in a statistical sense
- See Errico et al. (2013, QJRMS), Privé et al. (2013, QJRMS)
An OSSE for MISTiC™ Winds

- Constellation of microsats providing high spatial-temporal resolution tropospheric temperature and humidity soundings
  - IR spectrometer sampling the ‘midwave’
  - AMVs derived from feature tracking in temporally subsequent retrievals
- Use the **GMAO OSSE infrastructure** to estimate the potential impact of both wind and radiance information from the constellation
  - RT coefficients for MISTiC instrument
  - proxy data based on existing instruments
  - simulator for wind retrievals
Simulating AMVs from model output

- NR feature tracking for winds not feasible
  - provides cloud fraction and RH fields, not trackable cloud or WV features
  - simulator developed to identify probability of “trackable” features in NR fields

- Radiance simulation from NR more straightforward
  - minor extension of existing OSSE radiance simulation
  - realistic radiances obtainable for clear and partially cloudy scenes
MISTiC simulated cloud AMVs

"Trackable" clouds identified in **NR cloud fraction fields**, with a probability function used to determine which might be effectively selected as observations

- **Trackable clouds**
  - Cloud pressure height below the tropopause
  - Cloud fraction in the range 20-80%, with increasing probability in the range 20-40%, and decreasing probability in the range 60-80%
  - Speeds greater than 3 ms^{-1}
  - Cloud fraction above less than 85%, assuming a vertical random overlap
MISTiC simulated water vapor AMVs

“Trackable” water vapor features identified in **NR relative humidity fields**, with a probability function used to determine which might be effectively selected as observations

- **Trackable water vapor features**
  - Located below the tropopause
  - RH gradient greater than 65%, estimated for each vertical level as the difference between the max and min RH value in a 35 km$^2$ box
  - Speeds greater than 3ms$^{-1}$
  - Cloud fraction above less than 85%, assuming a vertical random overlap
MISTiC™ OSSE experimental configuration

Control GMAO OSSE
• Full observing system c.2016
• GEOS model C360L72 (28 km)
• GSI analysis 3dVar (56 km)
• July – Aug cycled experiment

Experiment - 1PERF
• Control + 1 orbit, 3 satellites
• MISTIC radiances, 46 channels
• MISTIC AMVs, cloud and WV
• Perfect MISTIC observations

Experiment - 1ERR
• Like 1PERF, but obs errors applied to MISTiC radiances, AMVs

Experiment - 4PERF
• Like 1PERF, but 4 orbits, 12 satellites

Experiment - 4ERR
• Like 1ERR, but 4 orbits, 12 satellites

Focus here mostly on 4-orbit experiments
Simulated MISTiC AMVs

- Himawari-8 AHI used as proxy to calibrate observation counts and assign error
- 6-h global coverage achieved with 4 orbital planes, 3 satellites in each
- Water vapor AMVs retrieved on constant pressure surfaces, with increased vertical resolution
  - allows mid-level retrievals
  - minimal height-assignment error
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Impact of MISTiC observations on the analysis

Zonally averaged u-wind analysis error variance

- Analysis error computed vs. Nature Run
- Difference plots: Blue (red) indicates adding MISTiC obs reduce (increase) analysis error
Impact of MISTiC observations on forecast skill

500 hPa anomaly correlation

- ACC computed vs. self analysis
- Neutral to small positive impact in all cases (top)
- Stippling shows 95% confidence in 4ERR over CTL (bottom)
Cloud and WV AMVs combined

- Near-uniform distribution of observations through much of the troposphere
- Largest impacts from observations at middle levels
Forecast sensitivity observation impact (FSOI)

24-hr Global Moist Energy, July–August

- Control OSSE observing systems show expected relative contributions
- Application of realistic errors reduces impact of MISTiC *radiiances* significantly...
MISTiC radiances FSOI by channel
MISTiC radiances FSOI by channel

Large reduction of impact points to remaining challenges in RT modeling for midwave T-channels: solar reflective effects

- Temperature
- Moisture

Perfect obs 4PERF

Imperfect obs 4ERR

Channel Index

% Error Reduction

- 550
- 500
- 450
- 400
- 350
- 300
- 250
- 200
- 150
- 100
- 50
- 1

% Error Reduction

- 3.5
- 3.0
- 2.5
- 2.0
- 1.5
- 1.0
- 0.5
- 0.0
- 0.5
- 1.0
- 1.5
- 2.0
- 2.5
- 3.0
- 3.5
Summary

• NASA is investing in several micro-sat concepts in various phases of research, development, and deployment for environmental monitoring and prediction (CYGNSS, IceCube, TROPICS, MISTiC, ...)

• The GMAO has the mandate and data assimilation infrastructure to support the development of micro-sat missions (in cooperation with instrument experts!)

• Results shown for MISTiC are not intended to be definitive, but rather an initial demonstration of how DA infrastructure can aid in mission design and assessment of impact
  • simulation of observables
  • error modeling
  • deployment/coverage scenarios
  • estimated impact

• Continued refinement of (investment in) DA capabilities and accompanying diagnostic infrastructure required to adequately assess the potential impact of proposed observing systems with ever increasing spatial and temporal resolution