On the Utility of Airborne MEMS for Improving Meteorological Analysis & Forecasting

John Manobianco & David A. Short

ENSCO Inc.
Aerospace Sciences & Engineering Division, Cocoa Beach, FL, USA

Objectives
- Improve weather analyses / forecasts using airborne Global Environmental MEMS Sensors (GEMS)
- Guide present / future design of GEMS for meteorological applications
- Assess cost effectiveness / life cycle support requirements for prototype GEMS

Simulation Models
- Advanced Regional Prediction System (ARPS)
  - Public domain software of choice for Analysis and Prediction of Storms
  - Three-dimensional, non-hydrostatic limited area dynamical model
  - Compressible Navier-Stokes equations for atmospheric flows
  - Storm-scale (0.00004 m) to regional-scale (100 km) weather phenomena
  - Comprehensive physical parameterizations:
    - Radiation, turbulence, clouds, precipitation
    - Surface heat, moisture, momentum fluxes & land-surface energy budget
  - ARPS Data Analysis System to generate initial condition
  - Data input & quality control
  - Objective analysis

Lagrangian Particle Model (LPM)
- Embedded in ARPS
- Track sensor position (x, y, z) each model time step (t△)
  - y(t△+t) = y(t△) + v(t△) t△
  - x(t△+t) = x(t△) + w(t△) t△
  - v(t△) = wind velocity vector
  - w(t△) = vertical velocity for gravitational settling
  - Two-way
  - Trackable-scale velocity components obtained directly from ARPS
  - τ, ν, ω: turbulent velocity fluctuations based on 1°-grid Model

- Sensible energy equation:
  - 0
  - Air density variations negligible

- Sensors treated as passive tracers moving independently of one another
- Sensors cannot advance further until impact at ground or carried beyond model domain

Analysis & Validation
- Impact of GEMS observations on weather analyses / forecasts
- Observing System Simulation Experiments (OBSAVE)
- Assess sensitivity to:
  - Multiple weather scenarios & deployment strategies
  - Sensor accuracy, resolution, distance & sampling frequency
- Simulation results help refine GEMS design specifications
- Data storage & processing
- Measurement accuracy for pressure, temperature, humidity
- Networking and navigation algorithms
- Communications environment

Summary / Future Vision
- Simulation studies – Proof of Concept
  - State-of-the-science Numerical Weather Prediction model
  - Lagrangian Particle Model (LPM)
- Deployment / evaluation of prototypes – Next Phase
  - Limited static / dynamic tests at selected sites (similar to Smart Dust tests by Poite et al. @ Berkeley)
  - Leverage resources by testing prototypes during multi-agency field experiments
  - Larger-scale deployments via unmanned aerial vehicles (UAV), balloons, aircraft
  - Assess environmental impacts
- GEMS: A revolutionary new observing technology for the 21st century - Future
  - Regional & global deployment for operational weather analysis / forecasting
  - Special deployments for military operations, hurricane reconnaissance, research experiments, etc.
  - Ultra high spatial / temporal resolution measurements available for any region of the world with active sensors

Motivation
- Economic incentives to improve weather forecasts & mitigate the impact of weather on life/property
  - $3 billion of the U.S. economy has weather sensitivity (e.g. aviation, construction, agriculture)
- Severe weather in the U.S. causes billions of dollars in damages annually
- In-situ observations not distributed evenly or densely enough around the globe... GEMS can:
  - Enable more complete coverage over oceans, high latitudes, & other data sparse regions
  - Provide means to assess more accurately the magnitude of regional global climate change
  - Monitor weather over politically sensitive regions including battlefield conditions
  - Remote sensors (e.g. satellites, Doppler radars) do not provide complete measurement suite
  - Satellite observations have limitations with vertical resolution, accuracy, and cloud obscuration

Virtual Weather Scenarios
- Historical weather data (hurricanes, etc.)
- ARPS + LPM provide simulated GEMS observation at any point in time / space

Case study (26 – 27 July 1997)
- ARPS / LPM configuration (CONTROL)
  - 5 km horizontal grid resolution (50 x 50 km² domain)
  - Surface wind / temperature (0 to 15 km)
  - Simulated data from 0000-2100 EDT 26 July
- Sensors released from 21 stations across Florida
  - 12 sensors placed at 50 m, 6.5 km increments from 0-9 km
  - 4 dual release periods (0000-1400 EDT 26 July)

3D Visualizations of Simulated Weather
- Florida East Coast Real Weather
- Florida East Coast Sim Weather

GEMS Observations / Trajectories
- Extract simulated observations of pressure, temperature, humidity, wind velocity
- Include random component to simulate measurement error
- Plot sensor dispersion / trajectories depends on weather scenario / deployment pattern
- Evaluate ensemble statistics & individual sensor observations for realism

Background in Hurricane Floyd (1859 EDT 14 Sep 1999)

Image produced by Dr. Dennis Chester (& Goddard Space Flight Center)