Enabling an Operational Coupled Modelling and Observing System to Assess Water Quality in the Lake George, New York Watershed

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Background

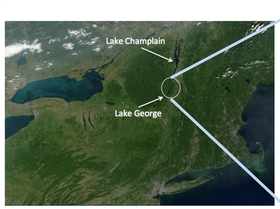
- One of the world's most pristine natural ecosystems with ~$1B annual tourism and recreation industry
- Understand and manage the impact from road salt, storm water runoff and invasive species
- Make the lake "smarter" with a coupled observational and modeling platform [The Jefferson Project at Lake George]

Lake Characteristics

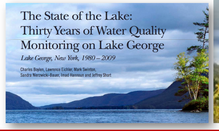
- Oligotrophic
- Dimictic
- Spring and tributary-fed with only one outlet at northern end
- Two basins connected by *The Narrows*
- Maximum depth of 57 m
- 395 islands

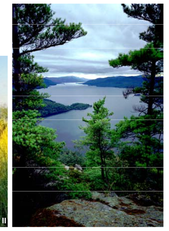
Watershed Characteristics

- New York State Adirondack Park
- Area: 617.4 km²
- Highest elevation: 806.5m
- Average drainage divide elevation: 411m
- Limited agriculture usage
- Population centers: Lake George Village (south), Ticonderoga (north)
- Over 90 in-flowing tributaries with eight accounting for about 45% of total inflow



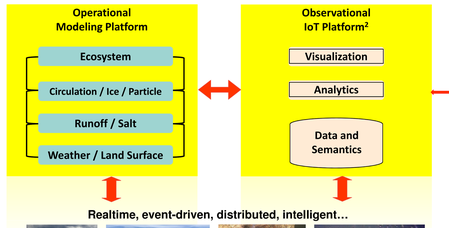
- 30-year longitudinal study highlighted three environmental stressors
  - Road salt (NaCl)
  - Nutrient loading via storm water runoff
  - Invasive species



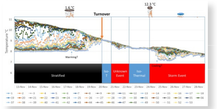


Approach

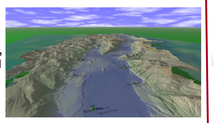
Coupled Operational Models with Data Assimilation and Validation



IBM/The Weather Company Mobile App: sensor data and model-based forecasts



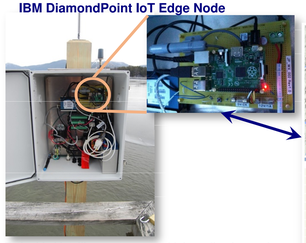
Lake Turnover



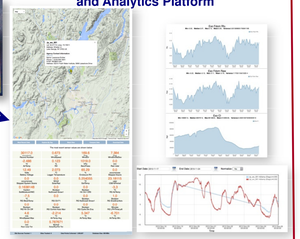
Watershed Topography, Lake Bathymetry and Sensor Locations

Observing System Platform²

IBM DiamondPoint IoT Edge Node



IBM AssemblyPoint Data and Analytics Platform

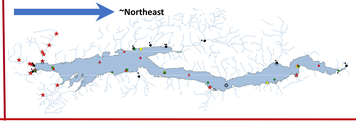


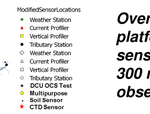
Embedded intelligence to ensure high quality data and advanced capabilities at the edge

- Live statistics (QA/QC)
- Analytics / AI prediction of the next data values
- Peer-to-peer engagement for data validation, event detection
- High frequency (live) casting data uncertainty analysis
- Automated, autonomous sampling plan optimization
- Model forecast driven decision making

Enterprise GIS / map based data platform

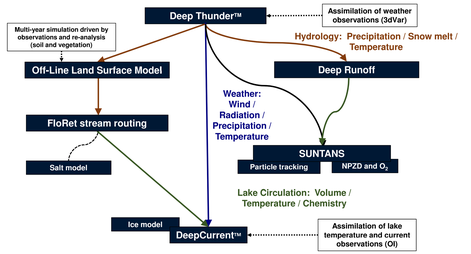
- Automated new sensor / data stream registration
- Live data analytics
- Automated plot generation
- Automated model forecast validation
- Model forecast engine interface
- Scenario engine interface





Over 50 sensor platforms, 500 sensors and 300 million observations…

Coupled Models[1]



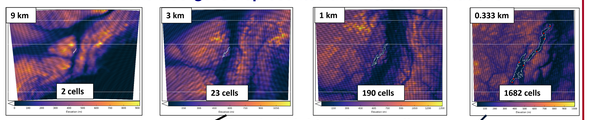
- Weather model enables atmospheric forcing for other models, predictions for operations and field work, and public outreach (Deep Thunder): △333m [based on WRF-ARW]
- Hydrology model to understand terrestrial runoff (precipitation and snowmelt, sediments, nutrients, contaminants such as salt) into the lake:
  - FloRet Stream Routing: 78 stream outlets (> 1000km length)
  - Deep Runoff[3]: △41m [based upon WRF-Hydro]
- Lake circulation model to understand transport (sediments, nutrients, contaminants, hydrodynamics and water quality
  - DeepCurrent: △50m with integrated lake ice [based on EFDC]
  - SUNTANS[2]: △~27 to ~70m
- Land Surface Model: △41m [based on NOAH-MP]
- Daily 36-hour operational forecasts with monitoring via Slack
- Automated visualization and validation

Weather Model (Deep Thunder)

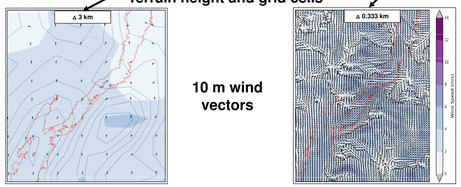
Model Description

- Based upon WRF-ARW 3.8.1 (WRF-DA, 3.6.1) https://www.mmm.ucar.edu/weather-research-and-forecasting-model
- 4 one-way nested domains: 9/3/1/.333 km [173x173/136x136/190x190/178x220] nested for 36 hours (40 vertical levels, with ~14 in the PBL)
- Run once daily (initialized at 00 UTC)
- Physics configuration
  - Thompson microphysics (includes explicit ice, snow and graupel)
  - Mellor-Yamada-Nakanishi-Niino (MYNN) PBL scheme with turbulent kinetic energy (TKE)-based local mixing and 2.5-order closure
  - NOAH land-surface modeling with soil temperature and moisture in four layers, fractional snow cover and frozen soil physics
  - Mellor-Yamada-Nakanishi-Niino (MYNN) surface layer
  - Grell-Devenyi ensemble cumulus physics for outer nest
  - RRTMG long- and short-wave radiation
  - Large Eddy Simulation (LES) for innermost nest (.333km)
- Data assimilation (3dVAR) of near-real-time surface and upper-air observations from MADIS and the Jefferson Project observing system
  - Surface stations, radiosondes, aircraft, ship, profiles, satellite, …
  - ~1500 stations: 9km nest (~1500), 3km nest (~600), 1km nest (~100), .333km (~10) – varies for each forecast
  - Additional quality control
- NASA high-resolution (2km) sea surface temperatures (SST), which include Lake Surface Temperature (LST) analysis over the Great Lakes
- NASA high-resolution (90m) Shuttle Radar Topography Mission (SRTM) terrain elevation
- MODIS 1km 20-category land-use data
- NASA 4km dynamic (daily) VIIRS Green Vegetation Fraction (GVF) data
- NASA 3km land surface fields for initialization
- NOAA Rapid Refresh (RAP) 13km analysis for background fields
- NOAA Global Forecasting System (GFS) 0.25° lateral boundary conditions

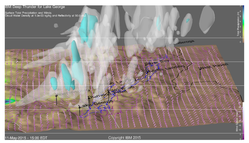
How Lake George Is Represented at Different Resolutions



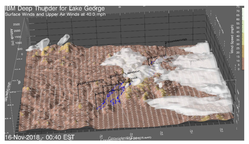
Terrain height and grid cells



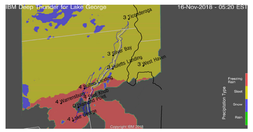
10 m wind vectors



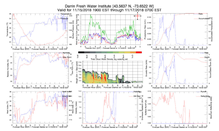
Example Predicted Volumetric Total Cloud Water Density and Reflectivity, 10m Wind Velocity, Total Precipitation, and Model Orography



Example Predicted Volumetric Wind speed, 10m Wind Velocity and Model Orography



Example Predicted Precipitation Type

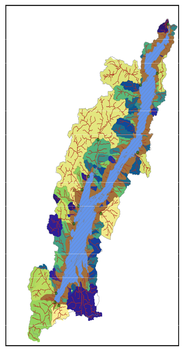


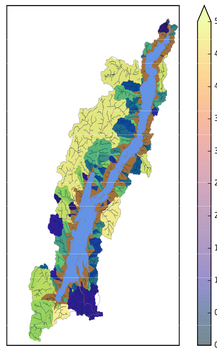
Example Site-specific Forecast Meteogram

Runoff Model[3]

Model Description

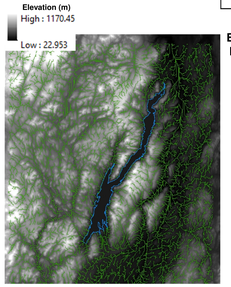
- Based upon WRF-Hydro 5.0 https://ral.ucar.edu/projects/wrf_hydro/model-code
- Reach-based stream routing
- Simulating flow through 1563 individual stream segments (reaches) in the Lake George watershed
- 182 that enter Lake George and are coupled to circulation models
- Horizontal resolution of 41m [1416 x 1752] (driven by 8:1 ratio from the 333m weather model nest)
- Land surface interactions simulated by Noah-MP
- Linked routing using Muskingum-Cunge channel flow



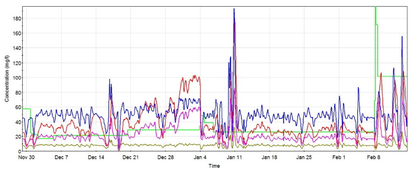


Model Domain Showing Basins (sub-watersheds), the Lake (light blue) and Stream Network (brown)

Example Predicted Streamflow Volume for 25 September 2018 0010 UTC (m³/sec)



Watershed topography (grayscale) with overlays of stream network (green and lake boundary (light blue)

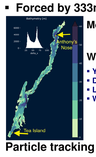


Example Simulated, Hourly Salt Concentration in Stream Segments

Circulation (and Ecosystem) Model

Model Description

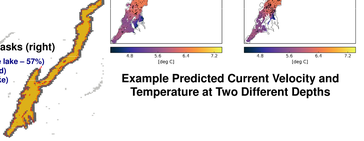
- Based upon Stanford Unstructured Nonhydrostatic Terrain-following Adaptive Navier-Stokes Simulator (SUNTANS) https://github.com/ofringer/suntans
- Horizontal resolution (~27 to ~70m, average ~47m)
- 57 vertical layers, ranging from 0.5m to 1.5m
- COARE V3.0 heat flux equations
- Mellor-Yamada 2.5 turbulence closure scheme
- Forced by 333m weather model nest



Model mesh bathymetry (left)

Weather and circulation land masses (right)

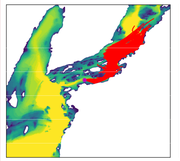
- Yellow (both circulation and weather are lake – 57%)
- Dark Grey (Circulation lake, weather land)
- Light Grey (Circulation land, weather lake)
- White (weather – land)

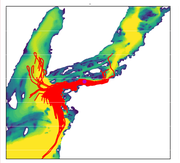


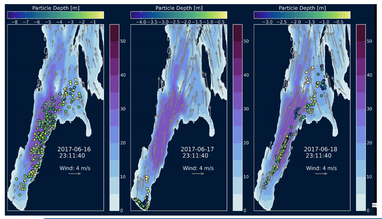
Example Predicted Current Velocity and Temperature at Two Different Depths

Particle tracking

- Tracks neutrally buoyant particles using circulation model output
- Generated as a post-process and is fast (300 particles for 24 hours ~2 min) → Can work interactively
- Can be modified to include behavioral patterns (e.g., fish, peculiar pollutant, etc., …)
- Example at different depths [~5m (top) and ~15m (bottom)] (lower left)
- Example (lower right): 3 releases of particles in the south of Lake George for 24 hours

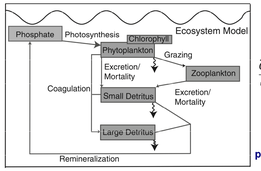






Simple Ecosystem Model

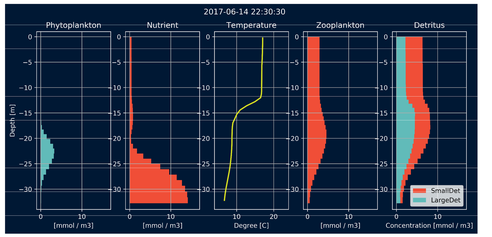
- Nutrients, Phytoplankton (∝ chlorophyll a), Zooplankton, Detritus, O_2 (Dissolved)
- Uses meteorological and hydrodynamic model output



Coagulation with other elements

$$\frac{\partial P}{\partial t} = \nu \cdot P - m_p \cdot graz \cdot Z - coag(D_s + P) - s_p \frac{\partial P}{\partial z}$$

Growth of phytoplankton | Phytoplankton fed upon | Sinking of phytoplankton



High concentration of phytoplankton sinks over time

Related Presentations

Software Engineering and Cyberinfrastructure for Environmental Processing:

- [1]11A.4: An Internet of Things Cyber-Infrastructure for the Study of Ecology of Lake George in the Jefferson Project (Thursday, 0900 - 0915)

Special Symposium on Meteorological Observations and Instrumentation:

- [2]786: An Internet of Things Cyber-Infrastructure for the Study of Impacts to the Ecology of Lake George in the Jefferson Project (Tuesday, 1600 - 1800, poster session)

Hydrometeorological Extremes Posters:

- [3]3A.8: Using WRF-Hydro v5.0 for Operational, Highly Localized Land Surface and Streamflow Predictions (Monday, 1600 - 1800, poster session)