THE NATIONAL ACADEMIES
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Board on Atmospheric Sciences and Climate

Recap: Forum on Cutting Edge Research and Development in the Observation, Understanding, and Prediction of Severe Weather

June 2008

The J. Erik Jonsson Center
Woods Hole, MA
June 5-6, 2008

Disclaimer*: This meeting recap was prepared by National Research Council (NRC) staff as an informal record of issues discussed during the Forum on Cutting Edge Research and Development in the Observation, Understanding, and Prediction of Severe Weather at the June 5-6 2008 meeting of the NRC's Board on Atmospheric Sciences and Climate (BASC). This recap is for informational purposes only. This document has not been reviewed and should not be cited or quoted, as the views expressed do not necessarily reflect the views of the NRC or BASC.*

BASC Members Present: F. Sherwood Rowland (Chair), M. Joan Alexander, Richard (Rit) Carbone, Walter F. Dabberdt, Kerry Emanuel, Greg Forbes, Peter Leavitt, John Snow, Tom Vonder Haar, Xubin Zeng

BASC Members Absent: Rosina Bierbaum, Antonio J. Busalacchi Jr., Carol Anne Clayson, Kirsten Dow, Dennis Hartmann, Isaac Held, Arthur Lee, Kirk Smith

NRC Staff Present: Chris Elfring, Rita Gaskins, Laurie Geller, Rob Greenway, Ian Kraucunas, Curtis Marshall

Other Participants Present: John Ferree, Brad Smull, Sam Williamson, Paul Markowski, Louis Uccellini, Russ Schneider, Gary Jedlovec, Dan Nietfeld, John Gaynor, Zoltan Toth, Bjorn Lambrigsten, Rick Rosen, Julie DeMuth, Yvette Richardson

SESSION 1: FIELD CAMPAIGNS IN SUPPORT OF IMPROVED UNDERSTANDING AND PREDICTION CAPABILITIES

NSF-ATM Contributions to Severe Weather Research: Context for VORTEX-2
Brad Smull, National Science Foundation, Arlington, VA

- Non-Tropical Severe Weather Topics in the National Science Foundation (NSF) Atmospheric Sciences Division (ATM)/Physical and Dynamic Meteorology (PDM) Portfolio

  - Tornadoes and tornadogenesis
  - Observation, simulation/forecasting, and relevant physics/dynamics of parent convective-scale storms
  - New technologies and intelligent warning systems design (e.g., Collaborative and Adaptive Sensing of the Atmosphere (CASA)ERC (Engineering Research Center) : $0.5M annual PDM contribution
  - Mesoscale convective systems (incl. "bow-echo" type severe windstorms, mesoscale convective vortex (MCV) production/impacts)
  - Atmospheric electricity (shares w/ ATM-Aeronomy)
  - Flash-flood producing storms (both over flat terrain and of orographic origin)
  - Hazards to aviation, incl. convectively-induced and clear-air turbulence (e.g., "lee rotor" circulations)

- Verification of the Origins of Rotation in Tornadoes-2 (VORTEX-2) Research Foci
  - Define role of downdrafts in tornadogenesis and their sensitivity to storm microphysics/ environmental thermodynamics
  - Accurately describe near-ground wind field in tornadoes and relationship between tornado properties (e.g., single vs. multi-vortex, asymmetries, duration) and resulting damage
  - Determine storm-environment & storm-storm interactions that are/are not favorable for tornadogenesis
  - Advance storm-scale numerical weather prediction for mesocyclone --> tornado scale; optimal use of observations via four-dimensional data assimilation (4DDA) schemes; improved analysis and prediction of pre-storm mesoscale environment

- VORTEX-2 Proposals: Principal Investigators (PI's) & Topics
  - Wurman & Rasmussen: VORTEX Scientific Program Overview (SPO)
  - Wurman, Trapp, Richardson & Markowski et al.: Collaborative Research: Multi-scale and Multi-Platform Study of Tornadoes, Supercell Thunderstorms and Environments in VORTEX-2
  - Weiss: Investigation of Storm-scale Baroclinity using Fine-scale Observations and Numerical Models
  - Bluestein: Radar Studies of Severe Convective Storms and Tornadoes
  - Frasier: Remote Sensing of Tornadoes and Storms with Mobile W-band Polarimetric and X-band Spaced-Antenna and Phased-Array Doppler Radar
  - Parker: Mobile Upsonde Measurements and Studies of Lower Tropospheric Processes
  - Atkins & Wakimoto: Damage Survey and Photogrammetric Analyses of Tornadoes, Mesocyclones, and Hook Echoes Observed During VORTEX2
  - Biggerstaff, Burgess, Mansell, Wicker & Ziegler: Multiscale Analyses of Tornadic Storms Using Multiparameter Mobile Radars
  - Straka & Rasmussen: Collaborative Research: Challenges in Understanding Tornadogenesis and Related Phenomena
  - Xue, Brewster & Gao: Study of Tornado and Tornadic Thunderstorm Dynamics through High-resolution Simulation, Advanced Data Assimilation, and Prediction

- Abridged Budget Perspective - FY07
  - Total ATM budget (including Lower Atmospheric Research Section (LARS) and Upper Atmospheric Research Section (UARS), excluding National Center for Atmospheric Research (NCAR) & major facilities): 140.3M
  - PDM Program budget: 21.9M

  - Inclusive of relevant NSF support of observational facilities (e.g., NCAR "Deployment Pool"), PDM-related activity accounted for ~25M
  - Anticipated outlays in support of VORTEX-2:
    - FY08 "Startup": 2.1M
    - FY09 1st Field Year: 2.5M
    - "Total" three-year investment 5.5+M
    - Note that tail of VORTEX-95 funding extended to FY03!
  - VORTEX-2 accounts for ~10% of PDM in FY08 - cf. all non-TC Severe Weather ~30%
  - Recent flat budgets have resulted in ~15% lost purchasing power during past several years - many deserving projects that cannot presently be funded

The VORTEX-2 Field Campaign
Presenters: Paul Markowski and Yvette Richardson, Associate Professors, Dept. of Meteorology, Pennsylvania State University, University Park

- Second highly coordinated field phase of an ongoing, broad investigation of tornadogenesis, tornado structure, and the relationship between tornadoes, their parent thunderstorms, and the larger-scale environment

- Dates: Spring, 2009 and (possibly) 2010

- Steering Committee:
  - Howie Bluestein (University of Oklahoma)
  - Don Burgess (Cooperative Institute for Mesoscale Meteorological Studies)
  - David Dowell (National Center for Atmospheric Research)
  - Paul Markowski (Penn State University)
  - Erik Rasmussen (Cooperative Institute for Mesoscale Meteorological Studies)
  - Yvette Richardson (Penn State University)
  - Lou Wicker (National Severe Storms Laboratory)
  - Josh Wurman (Center for Severe Weather Research)

- Relationship of VORTEX2 to National Research Priorities
  - Tornado warnings
    - Improvements in our understanding of tornadogenesis should better allow us to assess the likelihood of tornadoes in thunderstorms
    - Possible advances in our ability to forecast tornado intensity and longevity
- Climate
  - Relating future climate changes to possible changes in tornado frequency and intensity requires better understanding of how the large-scale environment of thunderstorms is related to tornado formation

- Numerical analysis and prediction (assimilation of storm-scale observations into numerical models)
  - storm-scale NWP essential in NOAA initiative to increase tornado warning lead time
  - semi-operational models now reaching convective scale
  - VORTEX2 datasets should become a testbed for numerical storm-scale prediction experiments

- Pre-VORTEX1 Methods
  - Visual observations
  - Fixed site instrumentation
  - Numerical simulations
  - Limited mobile assets

- Pre-VORTEX1 Understanding
  - Virtually all violent and most strong tornadoes are associated with supercells
  - Supercells are defined by rotational signatures (mesocyclones) generally identifiable on radar
  - Supercells acquire net cyclonic rotation *aloft* by tilting environmental streamwise (horizontal) vorticity in the updraft
  - Horizontal vorticity also can be generated baroclinically by buoyancy gradients associated with a storm's cool outflow, and the tilting of this vorticity can be important in the development of low-level rotation in supercells.

- Summary of VORTEX1 Findings
  - Increased awareness of the sensitivity of supercells to the near-storm environment
    - storm-boundary interactions
    - mesoscale variability away from obvious mesoscale boundaries
  - Modification of attitudes toward low-level mesocyclones
    - very large fraction of supercells contain circulations at low levels, and probably even at the surface
  - The thermodynamic properties of rear flank downdrafts may exert some control on tornado formation, intensity, and longevity
  - warmer downdrafts associated with tornadoes
  - Striking kinematic similarities between tornadic and nontornadic supercells on the mesocyclone scale
    - 88D at 30-60 km range: marginally resolves mesocyclone scale
    - VORTEX1: observed mesocyclone scale well, but sub-mesocyclone scale only marginally resolved and tornado scale unresolved
    - VORTEX2: should observe sub-mesocyclone scale well and perhaps marginally resolve tornado scale on some occasions

- Smaller field campaigns after VORTEX1
  - mobile dual-Doppler intercepts
  - tornado-scale radar observations
  - mobile mesonet intercepts

- Some unanswered questions in the study of tornadoes and tornadogenesis
  - Why do storms with seemingly similar structure differ in their tornado production?
  - *Why are the most intense mesocyclones not necessarily the ones most likely to be associated with tornadogenesis?*
  - What is the role of secondary gust fronts?
  - How valid is our understanding of the corner flow region and low-level structure of tornadic flow, which is based on laboratory studies, numerical simulations, and very limited observations?

    - How valid is our understanding of the corner flow region and low-level structure of tornadic flow, which is based on laboratory studies, numerical simulations, and very limited observations?
    - Does the structure of the tornado depend as predicted on swirl ratio?
    - Does the behavior of multiple vortices conform to predictions?
    - What is the relationship between observed winds and structural damage?
    - What is the vertical wind profile such that radar winds above the ground can be related to expected winds in the lowest layers where damage occurs?
    - What are the dynamical, thermodynamic, and microphysical natures of the interactions between supercells and other supercells? Between supercells and ordinary cells?
    - What types of cell interactions promote tornadogenesis? Can these scenarios be identified in an operational setting?
    - What types of cell interactions promote tornado dissipation and/or weaken the storm(s)?
    - What kinematic, thermodynamic, microphysical, and electrical changes occur in a storm as it crosses a low-level boundary?
    - As a mature storm encounters increasing environmental CIN (e.g., on the cool side of a boundary), how are low-level updraft strength and rotation affected?
    - How deep and strong are baroclinic zones associated with the anvil shadow?
    - What are the characteristics (magnitude and depth) of the low-level horizontal vorticity produced by these baroclinic zones?
    - What differences develop between the boundary layer eddies in the shade and those in the sunny environment?

- Some Needs
    - Integrated wind and thermodynamic data with high temporal resolution covering spatial scales from tornado to whole storm
    - Detailed analyses of the vorticity budgets of tornadoes and their antecedent circulations
        - precluded in the past by insufficient temporal and spatial resolution
    - Thermodynamic observations above the ground
        - Previously limited to a paucity of direct measurements made by soundings and suspect indirect observations from retrievals based on Doppler wind syntheses
    - Dual-polarization measurements to characterize hydrometeors, particularly in the rear-flank region
    - Observations in the corner flow region

- What has changed since VORTEX1?
    - Number of mobile radars (and experience of those operating them)
        - VORTEX1: ELDORA, P3, and DOW1 (only available for last 3 weeks of project, data unleveled, and only a couple elevation angles obtained)
        - VORTEX2: O(10) truck-borne radars available, some with rapid-scanning capability and some with dual-polarization
    - New in situ observing systems (ability to obtain some observations above the surface)

    - Communications/coordination capabilities

    - Data analysis techniques (ensemble Kalman filter technique was computationally unfeasible in 1995; it is being used widely today)
        - Diverse observations can be incorporated into an analysis in a dynamically consistent way (traditional dual-Doppler analysis will probably be replaced altogether soon)
    - New or improved fixed observing systems (will afford great opportunity to study storm-environment relationship)
        - CASA radar network
        - dual-polarization 88Ds
        - MPAR (Multipurpose phased array radar)
        - refractivity observations (88D and maybe CASA too)

- Summary
    - Decades of severe storms research has resulted in conceptual models of tornado structure and genesis.
    - Many of these conceptual models cannot be fully evaluated with existing datasets.
    - VORTEX2 will provide the opportunity to collect a comprehensive dataset of wind and thermodynamic measurement with high spatial and temporal resolution spanning several scales of motion.

The Observing System Research and Predictability Experiment (THORPEX): Supporting Advances in High-Impact Weather Research and Prediction
Presenter: Rick Rosen, National Oceanic and Atmospheric Administration (NOAA), Climate Program Office

- An element of the World Weather Research Programme
- Accelerating improvements in the accuracy of one-day to two-week, high impact weather forecasts for the benefit of society, the economy, and the environment
- 10-year (2005-2014) international research and development program
- Global weather component of GEO
- Guided by international science and implementation plans
- Desired outcomes include:
    - Extending the range of skillful weather forecasts to time scales of value in decision-making (up to 14 days) using probabilistic ensemble forecast techniques
    - Developing accurate and timely weather warnings in a form that can be readily used in decision-making support tools
    - Assessing the impact of weather forecasts and associated outcomes on the development of mitigation strategies aiming to minimize the impact of natural disasters
- Improved Understanding of Atmospheric Processes and Phenomena
    - Tropical-extratropical interactions
    - Extratropical transition of tropical cyclones
    - Tropical processes
        - Organization and maintenance of tropical convection
        - Madden-Julian Oscillation
    - Polar-midlatitude interactions
    - Aerosols

- Science of Prediction
  - Reducing and accounting for model inadequacy
  - Data assimilation
  - Observing systems
    - Observation system design
    - Observability
    - Adaptive observing and predicting observation impact
  - Intrinsic midlatitude predictability
  - Error dynamics of ensemble prediction systems

- Societal and Economic Research and Applications (SERA)
  - Components identified in U.S. Science Plan
    - Use of information in decision making
    - Communicating forecast uncertainty
    - User-relevant verification
    - Quantifying the value of weather forecasts
    - Developing decision support tools and systems
  - Focused opportunities for SERA
    - Probabilistic ensemble forecast techniques
      - Communicating forecast uncertainty
      - Developing decision support tools and systems
    - Regional field campaigns
      - Quantifying the value of weather forecasts
      - User-relevant verification
  - Initial activities
    - Joint NSF-NOAA solicitation on hurricane social science
    - NASA research announcement for weather applications

- International and Regional Activities
  - THORPEX Interactive Grand Global Ensemble (TIGGE)
    - Global ensemble forecasts from 10 operational NWP centers
    - Data archived at 3 locations: European Centre for Medium Range Weather Forecasting (ECMWF), NCAR, Chinese Meteorological Agency (CMA)
    - Prototype for Global Interactive Forecast System (GIFS)

- North American Ensemble Forecasting System (NAEFS)
  - Combines global ensemble forecasts from Canada & USA with distribution to Mexico
  - Operational implementation: May 2007

- THORPEX Pacific-Asian Regional Campaign (T-PARC)
  - Summer T-PARC: August-September 2008
    - Asian impacts from heavy rainfall, typhoon, and extratropical transition (ET)
    - Downstream effects on North America and Europe
      - Tropical cyclone recurvature and ET
      - Tropical and midlatitude predictability

        - International collaboration: U.S. (NSF, ONR), China, Japan, S. Korea, Taiwan, Germany, France, Canada, and U.K.

    - Winter T-PARC: January-March 2009
        - Impact of waves from western Pacific on weather over North America and Arctic
        - Linked to International Polar Year (IPY)
        - International collaboration: U.S. (NOAA, ONR, NASA), Canada, Mexico, Japan, and Russia

THORPEX Targeted Observations in Support of Improved Prediction of High-Impact Weather Events
Presenter: Zoltan Toth, NOAA/National Weather Service (NWS)/ National Centers for Environmental Prediction (NCEP), Camp Springs, MD

- THORPEX Pacific-Asian Regional Campaign (T-PARC)
    - Winter Phase
    - Winter Storm Reconnaissance Program
        - Operational since January 2001
        - Objective: Improve Forecasts of Significant Winter Weather Events Through Targeted Observations in Data Sparse Northeast Pacific Ocean
        - Good example of Operations to Research (O2R)
        - Information from operations used to conduct mission oriented research

- OPEN QUESTIONS
    - How far can the time limits of dynamical targeting methods be pushed?
    - How do linear assumptions limit current targeting methods?
    - How far can the lead time limit be pushed for targeting?
    - Medium-range forecasts?
    - What processes support Rossby-wave propagation?
    - What is the potential for adaptive use of satellite data?

- SCIENCE HYPOTHESES
    - Rossby-wave propagation plays a major role in the development of high impact weather events over North America and the Arctic on the 3-5 days forecast time scale
    - Additional remotely sensed and in situ data can complement the standard observational network in capturing critical multi-scale processes in Rossby-wave initiation and propagation
    - Adaptive configuration of the observing network and data processing can significantly improve the quality of data assimilation and forecast products
        - Regime dependent planning/targeting
        - Case dependent targeting
    - New DA, modeling and ensemble methods can better capture and predict the initiation and propagation of Rossby-waves leading to high impact events
    - Forecast products, including those developed as part of the TPARC research, will have significant social and/or economic value

- CONCEPT OF OPERATIONS: APPLY O2R CONCEPT TO SUPPORT RESEARCH PROJECT
    - Identify potential high impact weather events over NA and Arctic
    - Determine sensitive areas affecting verification events at different times
    - Observe conditions in sensitive areas
    - Assimilate all standard and adaptive observations
    - Generate new experimental products based on improved NAEFS system
    - Evaluate impact of adaptive observations and other NWP methods

- WINTER TPARC OBSERVING SYSTEM ENHANCEMENTS COMMITTED
    - Tibetan network
        - Expect to be up and running
    - Russian radiosondes – US Science priority
        - Partial funding for adaptive sounding secured
        - Negotiations with Roshydromet on operations
    - G-IV deployment to Japan
        - Dropsondes & radar
        - NOAA paperwork in progress
        - ATC & radio permit arrangements in progress
    - USAF Reserve
        - Dropsondes from C130s
        - Part of Winter Storm Reconnaissance deployment

- Under negotiation
    - QuikSCAT winds from Japanese Meteorology Agency (JMA)
        - Request through Japanese scientists

    - Office of Naval Research (ONR) P3
        - Couple flights with Wind Lidar measurements out of west coast being explored
        - Possibly with Canadian and NESDIS Wind Lidar WG support

- Opportunities for International Polar Year (IPY - THORPEX Collaboration Joint THORPEX-IPY Observing period –
    - Major opportunity for accelerating observing system design work
    - THORPEX is the weather component of IPY
    - Improved weather forecasts for polar regions & IPY activities
    - Scientific investigations:
        - Link between weather and climate processes
        - Mid-latitude – Polar interactions

- North American Ensemble Forecast System (NAEFS)
    - Configuration
        - NCEP membership increased to 20
        - Canadian major upgrade (incl. 20 members)
        - Downscaled forecasts
        - FNMOC ensemble to be evaluated

    - Product development
        - Products on Canadian / NCEP web page
        - Statistical post-processing

- Training / outreach
  - NA Regional Committee meeting
  - African outreach
  - NCEP & NWS plans to be developed: NWS response to NRC Forecast Uncertainty Report

- THORPEX Interactive Grand Global Ensemble (TIGGE)
  - Goal: Provide access to archived operational global ensemble forecast data
  - Contributions from ten global NWP centers
  - Archiving at three centers
    - CMA, ECMWF, NCAR
    - Data access is center specific
  - TIGGE Phase-2: Real time data access is new goal
    - Diverse data portals
    - Unified user interface

- Global Interactive Forecast System (GIFS)
  - Real time ensemble-based probabilistic products
  - New level of collaboration among global & regional NWP centers and scientific community
    - Joint development & use of algorithms / codes
    - Web based services etc

Participant Discussion of Current and Future Directions in Field Campaigns
(The following is an informal list of issues raised by one or more participants during discussion—they do not necessarily reflect the views of the NRC or BASC):

- Is there any effort to correlate wind (or maybe integrated wind) with damage, rather than vice versa, now that we have higher resolution data?
  - The VORTEX-2 proposal by Wurman and Alexander addresses this issue.
- Connection between lightning observations and severe weather/tornadoes and tornadoes; useful for watch/warnings?
  - VORTEX-1 (1994-95) included a lightning component. It was dropped from the plan, but there will be scientists with this expertise involved.
- Can numerical simulations now simulate tornadoes inside supercells?
  - Some tornado models get down to 10cm resolution, but these do not necessarily account for the large-scale environment; others do include larger environment, but only at 25m resolution or so; these may not resolve tornado formation mechanisms correctly. Also, an empirical trigger may be necessary (e.g., suddenly turning on friction) to get tornadoes to form. In other cases, it is "too easy" to get tornados to form--although this may represent a bias, (a sample skewed towards those simulations that actually produce a tornado). Examining otherwise identical pairs of numerical experiments that do/don't create tornadoes might be useful. Model microphysics schemes are also problematic (e.g., updraft temperatures). The key is better observations to constrain and validate model output.
- What is an "acceptable" ratio of false alarms in tornado warnings?

  - It has been a big challenge to improve detection capability without also increasing false alarm rate--which currently is somewhere around 85%. Current strategy for reducing false alarms is to provide more spatially-focused tornado forecasts/warnings.
- The need for a better benchmark/test for skill of tornado modeling and forecasting; also difficult to reproduce other groups' results.
  - We may be decades away from having the computing power to do real-time "nowcasting" of tornadoes. It is still important, however, to include operational forecasters in these research efforts.
- What about precipitation measurement benefits (of the THORPEX aircraft recon program)?
  - Much more difficult to observe/evaluate using macro-statistics; yielded no net benefit.
- Corrected/downscaled forecast numbers are impressive, but there are two interpretations: one is that the nested model used to provide the downscaling is good; the other is that original ("parent") model is really bad
  - Today's parent models do not have very large biases, thus bias correction may have less of an impact on the outcome than the the downscaling model technique itself, which could have a huge impact. Benefit of employing ensemble/bias correction is generally realized after about 3 days into the forecast.
- Q: What about the driftsonde system?
  - A: These are only used during the summer phase of THORPEX, even though one could argue that there is better potential for benefit during winter phase.

SESSION 2: NEW OPERATIONAL PRODUCTS AND SERVICES

Advancing Long Range Prediction for Extreme Events
Presenter: Louis Uccellini, Director, NOAA /NWS/ NCEP, Camp Springs, MD

- Context: Currently NCEP is running more than 40 runs per day going 16 days out, and we are in the process of trying to go to over 100 per day…
  - NOAA Seamless Suite of Forecast Products Spanning Climate/Weather/Water
    - Weather and climate communities need to start coming together to deal with forecasts beyond two weeks and the weather impacts of climate change; there are lessons to be learned in both directions.
    - Service center perspective…
    - NCEP model perspective…
  - NOAA's NWS Model Production Suite
    - Code Origins…
- Service – Science Linkage with the Outside Community
  - Each NCEP Service Center has a science support branch or technique development unit.
  - Also have established Test Beds throughout NCEP
- Examples of predictions of extreme events
  - Forecasts are ensemble-based, being issued with increasing lead time and certainty
  - April 16, 2007 Nor'easter: significant precipitation events (e.g., heavy flooding in New Jersey)

        - decent forecast seven days out
        - disruptive storm predictions as early as 4-5 days
        - prompted lots of people to take action
    - Pacific Northwest winter storms: December 1-3, 2007 and January 4-5, 2008
        - Both were record-breaking storms predicted 7-8 days in advance
        - Ten feet of snow predicted 3 days in advance in California
        - Forecast derived using a collaborative approach through all NWS forecast offices
        - Used Madden-Julian Oscillation (MJO) Update produced each week by Climate Prediction Center
    - Super Tuesday tornado outbreak, February 5-6, 2008
        - Deadliest event since 1985: 63 tornadoes, 57 fatalities
        - Outlook issued 6 days prior
        - Probability of Detection (POD) 100% for tornadoes occurring in Storm Prediction Center (SPC) watches
        - average warning lead time 17 minutes
- Reasons for success
    - Limits of predictability: in 1970s, there were opinions expressed to "abandon research that uses weather sequences generated in a computer as bases for deduction about the real atmosphere"…how did we get from Cressman's 12-hour limit to one week plus forecasts of extreme events?
    - Global observing system
        - Increasingly dominated by satellites
        - Sample
    - Science / modeling
        - Remote sensing and data assimilation techniques
        - Increasingly encompassing an Earth System approach
        - Multi-model ensembles
        - Improved physics/higher resolution models
    - Computing Capacity
        - Pushing the envelope of computer speed and storage
- Forces for Change Through 2015
    - Increasing emphasis on multi-model ensemble approaches that build on the NCEP model suite
        - Short Range Ensemble Forecast (SREF)
        - North American Ensemble Forecast System (NAEFS)
        - Climate Forecast System (CFS)
    - Entering the National Polar Orbiting Environmental Satellite System (NPOESS) era
        - More rapid access to hyperspectral data
        - Global Positioning System (GPS) soundings
        - Higher resolution surface radiance data
    - All models run within Earth System Modeling Framework (ESMF)
        - Models run concurrently
        - Hybrid vertical coordinate
        - Coupled
        - Spanning all scales
    - Operational Earth System model
        - more explicit hydro, climate and ecosystems applications
        - Next-generation (phase four - 2015) prototype of Weather, Ocean, Land & Climate Forecast Systems has computing factor of 81x.

- Challenges Facing the R2O (Research to Operations) Process
  - To accelerate research to operations, support “operations to research”
    - Test Beds
    - Computer capacity
  - Criteria for operational implementations must be more clearly defined
  - Boundaries between “research” and “operational” agencies: benefits of supporting research in the operational framework
  - Operational infrastructure is in some sense ahead of the curve (especially for data assimilation and multi-model ensembles; e.g., THORPEX)
- NOAA Center for Weather and Climate Prediction facility currently being built

New Products and Services at the Storm Prediction Center
Presenter: Russ Schneider, NOAA/NWS/NCEP/SPC, Norman, OK

- Forecast service advances over the past decade
  - Hazardous phenomena include
    - Tornadoes, Hail & Wind
    - Fire weather (Day 1- 8)
    - Winter weather
    - Excessive rainfall
  - Severe weather outlooks through Day 8
    - Exploit ensembles to produce probabilistic information through day 8; earlier efforts emphasized categorical outlooks
    - Day 4-8 Convective Outlook
      - Operational since March 2007
      - 30% Probability of an Event within 25 mi of a point (“high end” Slight Risk)
      - Not issued when potential or predictability are too low
    - Day 2-3 Convective Outlook
      - Operational since: 2001 & 1986 (categorical); 2001 & 2000 (probabilistic)
      - Hatched Area --- 10% or greater chance of an extreme event (EF2 or greater tornado, 2” or larger hail, 65 kt or faster gust)
    - Day 1 Convective Outlook (categorical - 1955, probabilistic - 2000)
      - Probability of individual hazards within 25 miles of a point
      - Operational since 1955 (categorical) & 2000 (probabilistic)
  - Verification of probabilistic output (tornados and hail)
  - Watch Hazard Probabilities - All watches do NOT have the same risk
- Science infusion & collaboration
  - National Weather Center - collocation with other entities
  - Examples of Organic (day-to-day) Science Infusion Activities
    - Severe Storm Environment Relational Database
    - Context-based Verification
- NOAA Hazardous Weather Testbed
  - Two main program areas
    - Experimental forecast program
    - Experimental warning program
  - Contributions to Advances in SPC Operations
    - SREF
    - Global Ensemble Forecast System (GEFS)

        - Convection Allowing High Resolution Numerical Weather Prediction (NWP)
    - Example: Severe weather event of April 7, 2006
        - SREF environmental guidance increased forecaster confidence leading to a “High Risk” Day 2 outlook
        - Impact: More than 800 total severe reports, including 3 killer tornadoes
    - Experimental Storm Scale Ensemble Forecast (SSEF)
        - Hazardous Weather Testbed (HWT) Spring Experiment, focused on experimental high-res Weather Research and Forecast Model (WRF) forecasts since 2004 (dx ~2-4 km)
        - Convection allowing ensemble forecasts (2007-2009) to address uncertainty
            - 10 WRF members, 4 km grid length over 3/4 CONUS
            - Major contributions from: SPC, National Severe Storms Laboratory (NSSL), University of Oklahoma, NCEP/Environmental Modeling Center (EMC), NCAR
        - Evaluate the ability of convection allowing ensembles to predict:
            - Convective mode (i.e., type of severe wx)
            - Magnitude of severe type (e.g., peak wind)
            - Aviation impacts (e.g., convective lines/tops)
            - QPF/Excessive precipitation
            - Year 1 Objective (2007): Assess the role of physics vs. initial condition uncertainty at high resolution
        - Convective mode: Besides simulated reflectivity, need a quantitative tool for supercell detection and strength in deterministic and ensemble forecasts
        - Convective Mode Prediction: Linear
            - Determine contiguous areas exceeding 35 dbZ
            - Estimate mean length-to-width ratio of the contiguous area; search for ratios $\geq$ 5:1
            - Flag grid point if the length exceeds: 50, 100, 200 miles
    - Calibrated Products at SPC
        - Use large-scale environmental forecasts to calibrate (i.e., statistically post-process) the ensemble and downscale to phenomena of interest
            - Probability of Thunderstorms (Cloud-to-Ground Lightning)
            - Probability of Severe Thunderstorms (Reports)
            - Probability of Dry Thunderstorms (Lightning & Relative Humidity)
            - Probability of Snowfall accumulation Meteorological Assimilation Data Ingest System (MADIS)
        - Wide range of high impact SREF guidance are available at the SPC website
- Challenges for Severe Weather
    - Enhance Operations – Research Collaboration
        - Support Testbed Infrastructure Research-to-Operations (R2O) and Operations-to-Research (O2R) and staff
        - Increase Participation through AO Process (travel & research support)
        - Reward Effective Collaborators: Operational Meteorologists, Government and Academic Researchers
        - Experimental Data Flows & Workstations (GOES-R Proving Ground)
    - Invest in NOAA Computer Capacity
        - Harvest Potential of Storm Resolving NWP

        - Deterministic & Ensemble

Storm-Based Warnings: Communicating Effectively with the Public
Presenter: John Ferree, Severe Weather Focal Point, National Weather Service, Norman, OK

- Storm-based warnings overview
    - Benefits include:
        - More specific
        - Increased clarity
        - Supports new dissemination technology
    - Example: Storm-based warnings implemented October 1, 2007
        - Three simultaneous tornadoes within line of severe thunderstorms

    - Performance measure implications
        - From 1987 to 2007, tornado warning:
            - Lead time increased from 5 min. to 13 min.
            - Probability of detection (accuracy) increased from 40 % to 78%
            - False alarm rate from fell from 80% to 76%
        - Storm-based warnings
            - Reduce the area unnecessarily warned
            - Are not expected to improve historical performance measures (Lead Time, Probability of Detection and False Alarm Rate)
        - Lots of ways to measure success
            - POD(Accuracy)
            - Lead Time
            - FAR
            - Reduction in False Alarm Area
            - Qualitative Assessment
- Active year - How are we doing?
    - 2008 - Now at 110 tornado fatalities, most since 1998
        - Super Tuesday Outbreak – Feb 5/6
            - 214 Tornado Warnings
            - Accuracy (POD) = >90%, Ave. Lead Time = 17 minutes
            - 56 Fatalities, 391 Injuries, $0.5 Billion damages
        - Mother's Day Outbreak - May 10/11
            - 120 Tornado Warnings,
            - Accuracy (POD) > 90%, Ave. Lead Time > 17 min
            - May 10: EF4 from Picher, OK to Neosho MO; 75 mile path
            - 391 Injuries, 22 fatalities, 200+ Injuries
            - May 11 - Multiple EF1 to EF3 in MS/AL/GA
        - Memorial Day Weekend: Sunday, May 25
            - EF2 up to EF4-5, 43 mile path length in Iowa
            - 6 Fatalities, >70 injuries
- Improving severe storm services
    - Improved dissemination via digital technology
        - Common Alerting Protocol (CAP)
        - Geographic Information Systems (GIS)
        - Digital Emergency Alert System (EAS)
    - Forecaster training - Instill "best practices"

        - Warning Decisions based mainly on:
        - Analysis of closest radar -- reflectivity & velocity at all elevations angles; algorithms used mainly as a "safety net"
            - Near storm environment
            -
            - Storm spotters
    - New visualization tools
        - Four-dimensional stormcell investigator (FSI)
    - Improved radar data
        - Range/Velocity Ambiguity Mitigation
        - Addition of Super-Resolution WSR-88D
        - Addition of other Radars (FAA and others)
        - Dual Polarization Upgrade
            - Upgrade starts in ~late 2009
            - Field product evaluation completed
            - Hydrometeor classification
            - Better remote QPE
            - Numerous visualization and training challenges
        - New Multi-Radar/Multi-Sensor Gridded Algorithms
        - Less range folding
    - Mobile consumer trends
        - Cell phones becoming even more important than TV, computers, especially among younger generations
    - IEMchat User Interface
        - Sample
    - Tornado Risk in Vehicles
        - Challenge of getting information to remote users
        - Some private companies starting to provide this information
- NWS Vision for the Future
    - Neighborhood-scale warnings
        - 45- to 60-minute tornado lead time
        - 1- to 3-hour flash flood lead time
        - False Alarm rates below 50%
    - Objectives
        - Increasing precipitation estimation accuracy
        - Fewer deaths and injuries
    - Hazardous Weather Testbed
    - Improving Warning Performance
        - New policies, processes, and procedures
        - Recognition of societal changes
        - Technology improvements
        - Ambitious warning improvement goals
        - Attractive paths for future development

A NWS Field Perspective: The Science and Operations of Warning the Public
Presenter: Daniel Nietfeld, Science and Operations Officer, National Weather Service Forecast Office Omaha, Nebraska

- 4 pieces to the warning puzzle

  - Radar
  - Environment
  - Ground truth: spotters
  - But the "Decision" is a Human Element
    - For the forecaster:
      - Tornado or Severe Thunderstorm Warning?
      - For how long?
      - For what geographic area?
      - Specific messages to emphasize?
      - What is at stake ?
      - Exactly who will be impacted by this ?
      - Are people awake/sleeping/driving/etc… ?
      - Have I already "missed" earlier storms ?
      - Am I making this decision entirely on my own ?
      - Are there any pre-existing negative (or positive) public perceptions of us / me ?
      - How will this information be received ?
    - For the warning recipient
      - Will my friends/family be hit ?
      - Will I (we) be hit ?
      - What has happened up to this point ?
      - Have there already been fatalities ?
      - What is the TV Station saying ?
  - Important issues / factors
    - Training
    - Research
    - Outreach
    - Experience
    - Technology
    - Resources
    - Lead Time
    - Threat
    - When/Where
    - Call to Actions
    - Emphasis
    - Validation

- NWS Service Assessments
  - Service Assessment (SA) Teams are activated to evaluate the NWS performance during significant high-impact events
  - Thorough *internal* Inspection of the operations that took place inside the WFO
  - Thorough *external* assessment with various users of the information
  - Quantitative assessment of the impact of the event
    - Fatalities, injuries, evacuations, damage, etc…
  - Qualitative assessment of the impact of the event
    - Actions taken, changes made, etc…
  - Components External to NWS: not to evaluate, but to learn from
  - Ultimate Goals
    - How to improve the NWS mission of "protecting life and property"
    - Lessons learned
    - How to make improvements

        - How to focus our resources
        - Training and Outreach initiatives
        - Identify Best Practices, Facts, Findings, and Recommendations

- SA Example: The Super Tuesday (February 5-6 2008) Tornado Outbreak
    - Charter Item: Assess new Storm-Basede Warnings (SBW) System
    - First giant outbreak since 1 Oct. 2007
    - *<u>549</u>* Warnings were issued
        - 335 Severe Thunderstorm Warnings
        - 214 Tornado Warnings
        - Flash Flood warnings <u>NOT</u> included
    - Examine each warning
    - Interview each WFO staff member
    - Evaluate warning operations/decisions:
        - Methodologies
        - Policies
        - Psychological mindsets
        - ANY factor that influenced the warning decision
    - General Conclusions: Points to Improve
        - Polygons were often too large
        - Polygons were not reduced in size when the storm moved into the far end of the polygon or out of the county
        - New warnings were sometimes late
        - Polygons were sometimes not truly storm-based, but still used county borders
    - General Conclusions: Points to Praise
        - Significant reduction in warning area resulted
        - Some warnings were quite specific and just for the threat area
        - Some positive user feedback was obtained (Caterpillar Plant Safety Mgr.)

Integrating Meteorology and Social Science: The NWS Service Assessment of the Super Tuesday Tornado Outbreak
Presenter: Julie DeMuth, National Center for Atmospheric Research, Boulder, CO

- NCAR Societal Impacts Program (SIP)
    - Mission: To improve the societal gains from weather forecasting by infusing social science research, methods, and capabilities into the planning, execution, and analysis of weather information, applications, and research directions
    - Little is currently known about:
        - Sources, perceptions, interpretations, preferences, uses, values, etc. of weather information
        - For various user groups
        - For a range of weather information contexts (e.g., weather phenomena, uncertainty, different points in time)
    - Examples of SIP research
        - Sources, perceptions, uses, and value of weather forecasts
        - Communicating uncertainty in weather forecasts
        - Broadcast meteorologists' preferences for conveying uncertainty and perceptions of public's needs and wants
        - Examining warning decisions in extreme weather events

        - Overall U.S. economic sector sensitivity assessment
        - Assessing the transportation sector's use and value of weather information (Lazo et al)
        - Examining the hurricane warning system: Content, channels, and comprehension *(proposed)*
        - Weather and Society * Integrated Studies (WAS*IS)
    - Super Tuesday tornado outbreak service assessment
        - Motivation
            - 56 "direct" fatalities; highest death toll since 1985
            - Despite extensive efforts to warn the public about the impending event, there was still a large loss of life. Why?
            - First time for societal impacts emphasis in a service assessment (and there has already been another!)
        - Ubiquitous questions
            - This was a well-warned event; why didn't people know?
            - Why didn't people plan better?
            - Why didn't people take shelter?
            - Why don't people do what they're *"supposed"* to do?
            - We get frustrated when we put "good" weather information out there and people don't make the "right" decisions!
        - Broader context: The "right" decisions … in life
            - Who is prepared for a terrorist attack, fire in your home, retirement, or dying?
            - What is the "right" decision? Is there a "right" decision?
            - How and why do decisions get made?
            - Bottom line -- If you want to study human beings, you'd better have a high tolerance for ambiguity!
        - Service assessment scope
            - Focus: To better understand why so many people died and the details of those fatalities
            - Opportunity to assess people's actual warning response behaviors and gather *empirical* information from survivors about their own knowledge, perceptions, decision-making
            - Can learn a lot by having people walk you through their knowledge, thoughts, and actions
            - Highly interdependent; iterative process
        - For the fatalities, wanted to gather info about:
            - age, gender, where they died,
            - whether warning was heard, warning source,
            - whether they heeded the warning, whether they sought shelter, whether safer shelter was available, etc.
        - For the survivors wanted to assess:
            - what information they had about the fatalities,
            - what information people had about the severe weather situation and how they interpreted that information (knowledge),
            - how people perceived the situation (perceptions),
            - what decisions people made (decision-making)
        - Methodology
            - Semi-structured interviews with members of the public
            - Blend of targeted, convenience, and snowball sampling

            - Conducted 41 interviews in the 6 WFOs visited (assessment team broke into 3 sub-teams)
        - Some of the questions
            - When did you first realize there was a threat of a tornado in this area? (e.g., How did you learn about the threat? What were you thinking after you received that information? What did you do next?)
            - Have you ever been in a similar type of extreme-weather situation in the past?
            - Is there any other information you would have liked to have had?
        - Findings – knowledge
            - People get information from multiple sources (most commonly via television, also commonly from other people)
            - People get information multiple times
            - NOAA Weather Radio not common
            - Misconceptions about sirens
        - Findings – perceptions
            - Integration of seasonality, weather salience, situational awareness about the event
            - Personalization of the threat: Seeking confirmation of the threat, personal risk perception (optimism bias!)
        - Findings – decision-making
            - Often think of decision-making as a singular event
            - Happens numerous times and ways throughout the warning process
            - Implicit part of people's gathering and interpreting weather information
            - Focusing on sheltering: Vast majority of people who received warning information sought shelter in best location available to them
        - Findings – 56 fatalities
            - Collected as much good data as we could
            - Nearly 2/3 of victims were in mobile homes
            - Distinction between "safer" and "safest" shelters (most people did not have a "safest" shelter option available)
            - Of 19 people for which we had information, most people heeded the warning and sought shelter in best available location
- Integrating Meteorology and Social Science
    - Great strides in meteorology
        - How has meteorology advanced in 15 years?
        - How have warning and forecast operations advanced since 1993?
        - We've undergone a paradigm shift of warning services
            - Extremely high expectations
            - Relatively proud confidence in meeting them
            - Will continue to advance and improve
    - The next great strides…
        - To create "good / effective" products and services for users
        - Provide people information that they *actually* want and use rather than what *we think* they do (or should) want and use
    - Integrating Social Science

        - Tremendous amount of knowledge --- concepts, methodologies, theoretical frameworks, tools --- from the social sciences that can and should be integrated!
        - Communication, sociology, psychology, economics, decision science, anthropology, etc.
        - Couple research efforts with product development efforts and practice-based knowledge
        - Critical to being able to provide improved products and services to help inform and improve people's decision-making
    - Many needs and opportunities
        - Knowledge gaps regarding people's sources, perceptions, interpretations, preferences, uses, values, etc. of weather information
        - Multiple users, creators, channels, messages, contexts
        - Vortex II and THORPEX
        - Probabilistic warnings
        - Providing forecast and warning information via new media (cell phones, PDAs, in vehicles, etc.)
        - Future NWS service assessments and other storm damage assessments
    - Partnerships & interest are essential
        - Partnerships among social scientist, research meteorologists, operational meteorologist, policy makers, practitioners, etc.
        - Interest and willingness to work together, to listen, learn, exchange ideas to co-produce knowledge
    - A vision for the future
        - Need vision, optimism, ideas, entrepreneurs to pave the way forward
        - Need commitment – resources, people, support
        - Need to think long term and big (not going to find one single solution, not going to find solutions in the next 2 months)
        - Need to foster good, strong partnerships

Participant Discussion of Current and Future Directions for Operational Products and Services *(The following is an informal list of issues raised by one or more participants during discussion—they do not necessarily reflect the views of the NRC or BASC)*:

- Need for research into how the public views probabilistic forecasts, impact of "blown" forecasts, etc
- Examples of failures as well as successes?
    - Mother's Day this year was considered a failure (precipitation forecasts were okay but winds were way off; one fatality off DE coast)
    - Tendency to get storms in certain regions right, others wrong
    - Credibility is lost with the user community by consistently over or under-predicting the magnitude of weather events
- There has been huge progress, yet others see the huge amount of work that still needs to be done; what is the rationale for saying more needs to be done while not over-selling the need?
    - Always room for improvement. The idea of multi-model ensembles did not initially get broad support. Now there are other things that need to be done to take advantage of multi-model ensembles For instance, need to know how many ensemble members are required to reduce uncertainty without wasting resources. Research community can address this question.

- How can ensembles be advanced even more, in multiple spheres? Also, with many different groups running many different models or "flavors" of the same model, could NCEP still serve as a clearinghouse for model output?
  - There is already some effort to do this, in real time, (e.g., the Climate Forecast System.) But there is a challenge in getting the research community to run models operationally. Good example: should we use one dynamic model with lots of different physics or completely different models? Data flow can be an issue. Also, what can you do centrally versus in a distributed manner?
    - Need a strategy behind doing ensembles
- What about satellites? How long do they last?
  - Typically at 5-7 year timeframe (even research satellites are routinely operating for more than 2-3 years). But it is often a guessing game figuring out how long they will last.
- Is there an obvious time of day / place / mode where you need to focus on forecast/warning improvements?
  - Yes, nighttime warnings are much more difficult to communicate to the public (new technology: bed shakers connected to tornado warning radio, digital TV that turns on your TV at night - there are privacy and security issues though). Improving vehicle safety is important. Substandard home construction is also a major issue, especially mobile homes.
- What are the theoretical constraints on accuracy/false alarms?
  - They certainly exist, need more research on this topic.
- How best to tap into private, nonprofit, university systems with relevant data?
  - Need more partnerships, e.g. with TV radars.
- Do forecasters need to have direct feedback from users for their job, or is that a role better suited to emergency managers?
  - Feedback is useful to forecasters and to product developers, because people do interpret and use information differently from how it is intended
  - Is it possible to separate creation of forecast information/database from the communication and translation of information for public use?
  - Meteorologists could perhaps focus on providing the best possible information, while information "translators" and those with expertise in communication focus on rather than on reformatting raw information to effectively serve user communities
- Effective communication –ultimately requires many people in many relevant roles
  - General public is composed of a very wide spectrum of individuals; may be easier for meteorologists to reach the people who can reach the public than to reach the public directly
- Meteorologists often provide very good forecasts with adequate lead times; another challenge involves reaching people (radios and sirens clearly aren't enough) and motivating them to take shelter when they should. Further improvements need to address the barriers/societal issues.
  - Also difficult to effectively insert yourself into the user's decision-making process
- Important to address the wide diversity of users and partners (distinction is important - partners are the ones who help you reach the users). Somehow you need to bin.
- Dealing with a human system, so no one single bullet to solve these problems.
- NOAA starting to build a capacity in social science, with both a research component and an operations component.

    - Surveys: US does the best job in the world in assessing damages, but the data is still very poor, need lots of additional capacity/expertise to do it right, both internally and in collaboration with external partners.
- How do people decide when a threat is over (leave their shelter)?
    - There are some example of people getting TOO much lead time, i.e. they came out of their shelter because they thought the threat was over

SESSION 3: NEW OBSERVATIONAL CAPABILITIES

GeoSTAR and Hyperspectral Observations

Presenter: Bjorn Lambrigtsen, Jet Propulsion Laboratory, Pasadena CA

- Observational needs, especially sounders & severe weather
    - Models: High resolution with correct/complete physics
        - Models must be improved with respect to diurnal cycle
        - Models must be improved with respect to convective microphysics
        - Model runs must be initialized with valid & complete observations
    - Observations: "Storm sensors" with frequent observations
        - Observations inside & below storm
        - Capture microphysics and mesoscale dynamics
        - Accurate real-time observations for diagnostics, assessment & analysis
        - Frequent/continuous observations $\Rightarrow$ GEO satellites, "dwelling" UAS
        - Full resolution of diurnal cycle
        - Complete storm life-cycle
    - Requires better fidelity, higher resolution, deeper penetration, vertical structure, continuous & complete life-cycle observations
- Infrared vs. microwave sounders
    - Spatial resolution
        - 10-15 km vs. 15-50 km horizontal resolution
        - 1-1.5 km vs. ~2 km vertical resolution
    - Basic sounding accuracy
        - 1 K vs. 1.5 K for T(z); 15% vs. 20% for q(z); none vs. 40% for L(z)
    - Scene coverage
        - Cloud free: IR outperforms MW (but IR = MW in coverage)
        - Partly cloudy: IR < MW (IR depends on "cloud clearing", a noise-amplifying process)
        - Fully cloudy, storms: MW far outperforms IR ("cloud clearing" cannot be done), although new algorithms should help
    - Hurricanes & severe storms
        - IR can only see cloud tops, often obscured by cirrus canopy
        - MW can see to surface (except in heavy precipitation: switch to convection algorithms)
    - IR is best suited for global observations and storm precursor conditions in clear sky
    - MW is best suited for observing in/through storms and precursor conditions in clouds
- Geostationary microwave sounder & applications

- Advantages of GEO MW Sounders
  - GEO sounders achieve high temporal resolution
    - LEO: Global coverage, but poor temporal resolution; high spatial resolution is easy
    - GEO: High temporal resolution and coverage, but only hemispheric non-polar coverage; high spatial resolution is difficult
    - Requires equivalent measurement capabilities as now in LEO: IR & MW
  - MW sounders measure quantities IR sounders can't
    - Meteorologically "interesting" scenes
    - Full cloud cover; Severe storms & hurricanes
    - Cloud liquid water distribution
    - Precipitation, convection & microphysics - vertical structure
  - MW sounders also complement IR sounders
    - Complement primary IR sounder (HES) with matching MW sounder
    - Until now not feasible due to very large aperture required (~ 4-6 m dia. in GEO)
    - Microwave provides cloud/"cloud-clearing" information
    - Requires T-sounding through clouds - to surface under all atmospheric conditions
  - A MW sounder is one of the most desired GEO payloads
- Applications of GEO MW Sounders
  - Weather forecasting: Improve regional forecasts; severe storms
    - All-weather soundings - standalone, but also complements IR soundings
    - Full hemispheric soundings @<50/25 km every ~ 15-30 minutes (continuous)
    - "Synoptic" rapid-update soundings => Forecast error detection; 4DVAR applications
  - Severe-storm diagnostics: Quintessential storm/hurricane sensor
    - Measure *location*, *intensity, vertical structure* of deep convection
    - Detect *intensification/weakening* in NRT, frequently sampled (< 15 minutes)
    - Measure all three phases of $H2O$: vapor, liquid, ice - including rain/snow
    - Measure stability under clear & cloudy conditions $\Rightarrow$ Detect severe-storm precursor conditions
    - Use for operational analysis & in research to improve microphysics of models
  - Rain: Complements GPM
    - Full hemisphere @ ≤ 25 km every 15 minutes (continuous) - both can be improved
    - Directly measure storm and diurnal *total rainfall*: predict flooding events
    - Complements GPM (TRMM): fill space-time gaps through "data fusion" methods
    - Measure *snowfall*, light rain, intense convective precipitation
  - Tropospheric wind profiling: NWP, transport applications
    - Surface to 300 mb; very high temp.res.; in & below clouds

        - Complements X-SCAT: merge surface & atmospheric wind products
        - Major forecast impact expected (OSSE planned) - particularly for hurricanes & severe storms
        - Air quality applications (pollution transport)
      - Climate research: Hydrology cycle, climate variability
        - Stable & continuous MW observations => Long term trends in T & q and storm stats
        - Fully resolved diurnal cycle: water vapor, clouds, convection
        - "Science continuity": GeoSTAR channels = AMSU channels
    - GEO/MW Sounder Is Broadly Justified
      - Called for in NRC Decadal Survey
- GeoSTAR/PATH: Precipitation and All-weather Temperature and Humidity
  - GeoSTAR = the PATH payload ≈ "Geostationary AMSU"
    - GeoSTAR will provide time-continuous MW soundings from GEO
    - Primary focus on *hurricanes & continental severe storms*
      - Addresses significant hurricane issues: now-casting, improved intensity observations/models
      - Significant synergy with *GOES-R (ABI, GLM), GPM, QuikSCAT-successor, LEO-sounders (MW & IR)*
    - Significant impact on regional and global *NWP*
      - Improved initial state under cloudy conditions, rapid-update assimilations & real-time diagnostics
    - Greatly-improved boundary layer, cloud and precipitation process *models*
      - Major science advances in the understanding of hydrology cycle, El Niño, monsoons and tropical cyclones
  - Recent mission studies commissioned by NASA and NOAA
    - Proven instrument concept meets measurement requirements and is ready for flight development
    - Mission development can begin before 2010, launch ready by 2014
    - Reasonable payload cost/mass/power (GeoSTAR is ~ $100M/200-kg/300-W class instrument)
  - NASA-NOAA teaming opportunity
    - Opportunity created by temporary cancellation of GOES-R/HES

    Unique opportunity to greatly enhance NWP and hurricane remote sensing at low incremental cost
  - Focus Themes:
    - Tropical Cyclones - improving hurricane intensity observations
      - PATH will allow continuous monitoring,
      - measurement of warm core anomaly,
      - rain rate measurements, convective intensity,
      - all-weather wind vector profiles
    - Convective storms and storm dynamics *(including Great Plains MCS storms, Florida Sea Breeze storms)*
      - Convection shows very strong diurnal cycle, poorly sampled by satellites, models show significant amplitude and phase errors.
      - Radar reflectivity is a measure of internal storm processes (Models get the equivalent radar reflectivity wrong due to faulty microphysics)
      - PATH will mimic precipitation/cloud radar
      - Diurnal cycle fully resolved

        - Convection/rain measured in RT
        - Atmospheric stability measured concurrently
        - use to diagnose/fix model deficiencies(initialize with current, complete state variables, re-initialize with current observations)
      - North American monsoon & hydrological cycle
        - Convection shows very strong diurnal cycle
        - Poorly sampled by satellites
        - Models show significant amplitude and phase errors
        - PATH fully resolves diurnal cycle,
        - Convection/rain measured in RT,
        - Moisture and clouds measured concurrently
      - Numerical Weather Prediction
        - Model deficiencies: clouds and convection, initialization issues.
        - Sparse and incomplete observations in storms leads to poor storm forecasts
        - PATH observations can be used to diagnose and fix model problems
        - Initialize with current, complete state variables, re-initialize with current observations, use nudging and phase-correction/4DVAR
      - Atmospheric Stability
      - Precipitation
      - Tropospheric Wind
      - Radar reflectivity
  - GeoSTAR System Concept
    - Aperture-synthesis concept
      - Sparse array employed to synthesize large aperture
      - Cross-correlations -> Fourier transform of Tb field
      - Inverse Fourier transform on ground -> Tb field
    - Array: Optimal Y-configuration: 3 sticks; N elements wide, One “Y” per band, interleaved
    - Other subsystems
      - A/D converter; Radiometric power measurements
      - Cross-correlator - massively parallel multipliers
      - On-board phase calibration
      - Controller: accumulator -> low D/L bandwidth
  - GeoSTAR Prototype Development (small, ground-based)
    - Objectives
      - Technology risk reduction
      - Develop system to maturity and test performance
      - Evaluate calibration approach
      - Assess measurement accuracy
    - Thoroughly tested at JPL; performance is excellent
- Notional PATH Mission
  - Objective: Observe US hurricanes & severe storms
    - CONUS severe storms, extratropical cyclones
    - Atlantic & E. Pac. hurricanes
  - ROI focused near E. Carribbean
  - Adequate sensitivity with GeoSTAR
  - Focus is on high-value soundings in cloudy/unstable conditions
  - Bonus: Synergy with GPM, scatterometer, GOES-R (ABI, GLM)
- Algorithm development

  - Field campaigns ⇒ New algorithms
  - Example: "HAMSR" MW Sounder on NASA ER-2 used for core observations of Hurricane Emily off Costa Rica in 2005
- GOES-R mission of opportunity
  - Currently there is no HES payload on GOES-R and GOES-S (and maybe -T)
  - HES slot is "kept open" as "Advanced Instrument" in S/C RFP
    - 210 kg + margin, 385 W + margin, large D/L bandwidth
  - NASA could develop and "demo" GeoSTAR on GOES-R/S
  - NOAA is strongly interested in a GEO MW sounder
    - Solidly documented basis for need
    - Internal and consultant assessments conclude that GeoSTAR is preferred payload
    - Strong user community interest
  - Use "Advanced Instrument" slot to demo new capability as MoO
    - MoO payload provided and managed by NASA
    - NOAA avoids programmatic risk/complexity/cost of "operational" systems
    - NASA gains opportunity to demo new payload at low overall cost
    - NOAA obtains "advanced sounder" in lieu of HES and also reaches long-term MW goal
    - Perfect opportunity to demonstrate new "Research-to-Ops" paradigm
    - Effective cost sharing
      - NOAA provides platform and launch services, only minor additional cost: ≈ freebie @ minimal risk
      - NASA provides payload
      - Total cost is about 1/3 of full mission cost
  - Requires negotiations & NASA-NOAA commitment/agreement
  - Time is short: GOES-R (~2014 launch) requires 2009 pre-Phase-A start and 2010 Phase-A start; GOES-S (~2016 launch) requires 2010 pre-Phase-A start and 2011 Phase-A start
  - GOES-R MoO Benefits and Challenges
    - Win-win opportunity for NOAA and NASA
      - Immediately leverage synergy with GPS, Scatt and GOES-R (ABI, GLM)
      - Address urgent severe-storm and hurricane issues
      - Improve regional weather forecasts
      - Immediate/temporary replacement for HES
    - NOAA meets strategic goal: "By 2010 determine best method for GEO/MW"
    - NASA is able to demo new capabilities and new technology at low cost
    - Both: Demo new FFRDC acquisition strategy for lower risk
    - Temporary window of opportunity: GOES MoO will exist only in the absence of HES: GOES-R and GOES-S (~2014–2018)
    - Research to Operations
      - Opportunity to demonstrate new paradigm for Research-to-Ops
      - Renew and refresh past NASA-NOAA collaborations
      - Satisfy congressional mandate and NRC recommendation
    - Significant challenges
      - Engaging high-level NASA and NOAA managers in discussions
      - Making timely decisions
      - Identifying funds
  - GOES-R MoO Next Steps

        - Urgent NASA-NOAA discussions needed
            - Programmatic goals
            - Decisions and commitments
        - Key programmatic issues must be addressed
            - Roles and responsibilities
            - Payload selection process
            - Implementation and funding (early access to funds to enable immediate start, rapid implementation, simplified programmatic structure - NASA ESSP model)
        - Schedule: Relaxed GOES-R/S need dates for MOO payload integration?
        - Risk management re: "operational mission" vs. "experimental payload"
        - NOAA must convey strong interest to NASA to facilitate funding & opportunity:
            - Encourage near-term IIP funding for pre-phase A risk buy-down
            - Encourage development funding through "SALMON" or "Venture" AO
            - Alternatively: NOAA must identify payload development funding (~$150M)
        - Technical issues
            - Platform resources
            - Interfaces
            - Accommodation and integration
            - Testing and compliance verification
    - Flexibility: Instrument options
        - The design is very flexible
        - There are several descope options that yield most of science
        - In general, the instrument can be sized to meet available resources
    - Flexibility: Accommodation options
        - There are many feasible options
        - GeoSTAR is essentially easy to accommodate
        - We will design to fit available space & resources
- Roadmap
    - Prototype: 2003-2006 - Fully functional system completed under NASA IIP - now tested & characterized
    - Continuing risk reduction: 2006-2010
        - Develop 183-GHz low-noise compact/lightweight multiple-receiver modules
        - Develop efficient radiometer assembly & testing approach
        - Migrate correlator design & low-power technology to rad-hard ASICs
        - New: Second IIP effort now funded (NOAA to provide matching funds)
    - Science and user assessment
        - Forecast impact: OSSEs under development
        - Algorithm development; applications
    - Development of space version (PFM): ~2010-2014
        - Start formulation phase in 2009
        - Ready for integration in 2013-15
    - Joint NASA-NOAA demonstration mission: ~2014-2016
        - MoO on GOES-R/S
          Transition to quasi-operational mode after 1 year in research mode

NASA's Short-term Prediction Research and Transition Program (SPoRT)
Presenter: Gary Jedlovec, NASA / Marshall Space Flight Center, Huntsville, AL

- Earth Science Office at Marshall Space Flight Center, Huntsville, Alabama
  - Collocated off-site in the National Space Science and Technology Center (NSSTC) with University of Alabama in Huntsville, Huntsville NWS Weather Forecast Office, private sector partners
  - Collectively, the scientists, faculty, staff, students, forecasters number about 175 people, making the this group one of the largest entities of its kind in Southeast U.S.
  - Collocation has fostered collaboration which has been the key to the success of our organizations for the last 15-20 years!
- The SPoRT Center – Infusing NASA Technology Into NWS WFOs
  - Mission of the SPoRT Center: Apply NASA measurement systems and unique Earth science research to improve the accuracy of short-term (0-24 hr) weather prediction at the regional and local scale
    - conduct focused research
    - evaluate in "testbed" mode
    - transition priority products to WFOs
  - External Partners: NWS (Southern Region, HQs), NESDIS (STAR, NDE), JCSDA, JPL, GSFC (GMAO)
  - Keys to success
    - Link data / products to forecast problems
    - Integrate capabilities into AWIPS
    - Provide training / forecaster interaction & feedback
- Interactions with WFOs
  - NWS Southern Region -- forecast problems
    - timing and location of thunderstorms, severe weather
    - diagnostic analysis of current conditions (esp. at night)
    - morning minimum temperatures (and its local variations)
    - fog and low cloud detection
    - coastal weather processes (sea breeze convection / temperatures)
    - off-shore precipitation processes
    - weather in data void regions
  - Match data / capabilities to forecast problem
    - Unique observations from MODIS, AMSR-E, and AIRS
    - Local lightning networks
    - Advanced modeling and data assimilation capabilities
    - GOES and other operational data
- Unique NASA Data to Operations
  - MODIS high resolution visible/infrared imagery – derived products
    - 4 times / day – full resolution, channels simulating NPOESS and GOES-R capabilities
    - TPW, LST / SST, cloud and fog products, composite imagery
  - AMSR-E products
    - rain rate, convective fraction, SSTs, TPW
  - Lightning Mapping Array (LMA) - source densities
  - AIRS temperature and moisture profiles (June 2008)
- Other Products
  - GOES aviation products (requested by NESDIS)
  - CSU/CIRA TPW and anomaly

    - NSSL WRF forecasts
    - Local WRF forecasts with MIA and MOB WFOs (2km, MODIS SSTs)
- Data dissemination via LDM
- SPoRT Programmatic Accomplishments
    - Established a working paradigm for transition of research capabilities to operations – a foot bridge over the "valley of death"
    - Regularly improve weather diagnostic and forecast capabilities at the WFO level
    - Developed user advocacy for new products, many of which will become future NOAA operational capabilities
    - Trained forecasters on use of new technologies
    - Developed, tested and transitioned various tools to collaborative organizations for application to their transition activities
    - Broadened partnerships to extend capabilities to new satellites and next generation weather display systems
- Improved Weather Forecasts with AIRS Data
    - Weather forecasting is an initial value problem – the better you represent the atmosphere / surface in the initial conditions, the better the forecast.
        - The North American Model (NAM) is the weather forecast model used by NOAA/NWS
        - NASA AIRS measurements detect important small-scale atmospheric temperature & moisture features
        - When properly assimilated into the NAM initial conditions, the AIRS measurements improve regional and local weather forecasts
    - Results / Impacts
        - 48 h NAM forecasts run 4x/day for a week show significant improvement in height anomaly correlations over control run
        - Recently document improvement in other forecasted parameters (clouds, precipitation, etc.)
        - Transition technologies for inclusion in operational forecast model – improved weather forecasts to the public
- NASA Land Information System (LIS) Software to Improve Land Surface Initialization in Regional Weather Models
    - Accurate specification of lower boundary conditions is critical to understand the hydrologic and energy cycles and weather forecasting
        - Fluxes of heat and moisture from the Earth's surface (land and ocean) influence low-level weather processes
        - High-resolution NASA satellite data and unique software applications which describe physical characteristics of the surface (moisture content, vegetation structure, etc.) can be used to:
            - improve the representation of these processes in atmospheric models
            - diagnose stressed or disaster prone regions (risk of fires, flooding, etc.)
    - Results / Impacts
        - Improved descriptions of surface parameters such as soil moisture can lead to:
            - more accurate predictions of diurnal temperature range, land / sea breeze circulations
            - improvements in other sensible weather elements such as clouds and precipitation

    - When fully test, new techniques to be transitioned to the broader weather community
- Total Lightning Data from NASA's Lightning Mapping Array: Severe Weather Forecasting
  - Demonstrating utility of NASA lightning data from ground-based systems helps ensure success of future satellite measurements
    - Severe weather affects the lives of most people in U.S.
    - Develop and advance the use of NASA total lightning data for severe weather forecasting
    - Ground-based systems serve as prototypes for advanced space-based systems
    - Improved severe weather forecasts – save lives
- Assessments and Product Surveys
  - Just don't throw data / products over the fence to end user!
    - match need (problem) to data/products (solution)
    - involve end users in the entire process
    - provide various types of training
    - assess utility and success
  - User surveys
    - when and how used
    - value added to the decision process
    - web-based, quick and easy to fill out
    - response stored in database for assessment
- The Next 5 Years
  - Continue to demonstrate utility of current and future NASA observations
  - AWIPS II and NPOESS
    - Transition current capabilities to AWIPS II (Fall 09)
    - Demonstrate for NPP by providing VIIRS and CrIMSS data and products to WFOs
  - Work more with regional centers – NSSL/HWT, HRD/NHC, NCEP/JCSDA
  - Explore additional collaborations beyond WFOs

The Weather Sphere: It's in the Air in Oklahoma
Presenter: John Snow, Dean, College of Atmospheric and Geographic Sciences, University of Oklahoma

- The Weather Sphere is
  - University, Federal, State, Private Industry, Friends
  - Collaborative weather and climate related entities, centered in Oklahoma and growing nationally and internationally to become the nation's center for weather-related education and training, research and development, and operations and services.
  - Weather Sphere programs are leaders in observing systems such as radar and surface-based instrumentation, data assimilation, mesoscale numerical modeling, forecast products and information, and societal applications.
  - The National Weather Center (NWC) is the anchor facility of the Weather Sphere and the University Research Campus.
    - 250,000 ft2 facility, opened in September 2006

        - Occupied by OU, federal, and state organizations with more than 550 employees, faculty, researchers and students focused on weather and regional climate
        - Adjacent to the NWC are Partners Place buildings housing private industry and university research units
- Surface Observing Systems
    - Core Weather Sphere capabilities in Integrated hydro-meteorological observation system planning, design, and deployment (OCS, NHDR, ARRC)
    - Oklahoma Mesonet - core capabilities in:
        - Collection, QA/QC, dissemination research-quality data in real time for operations and decision making (OCS)
        - Embedded urban, ag, air quality micronet(s)
- Radar
    - Weather Surveillance Radar - core capabilities in:
        - Doppler, dual-polarization, and phased-array radar technologies (NSSL, ROC, ARRC)
        - Radar refractivity → mesoscale moisture
    - Phased Array Radar
        - Basic science and engineering for the *Next* NEXRAD
        - Multifunction → point *and* distributed targets
        - Core capabilities in surveillance radar system design, development, and prototyping (NSSL, ARRC, CASA, LM/BCI)
    - CASA Radar Project: Collaborative and Adaptive Sensing of the Atmosphere
        - Partnership with U Mass in ERC
        - "Radar on a cell phone tower"
        - Capabilities: Distributed, collaborative, adaptive
        - forerunner of future "smart" sensing systems; reactive/proactive
    - Mobile radars: Capabilities in:
        - Mobile radar system design, development, prototyping and operation (NSSL, ARRC)
        - Dual-pol, rapid scan, phased array
- Radar applications
    - Radar Data Assimilation & NWP: Capabilities in
        - Radar data assimilation
        - Storm-scale numerical weather prediction (NSSL, CAPS, WDT)
    - Radar and Data Visualization: Capabilities in:
        - Doppler, dual-polarization, and phased-array radar data interpretation (NSSL, ARRC)
        - Integrated weather data visualization software (OCS, CSA, NSSL, WDT)
- Decision making: Core Weather Sphere capabilities in:
    - Award-winning meteorological decision making, application, education, and training (WDTB, OCS, SoM)
- Hazardous Weather Testbed
    - Brings everything together
    - Operated jointly each spring (NOAA + OU)
    - Transfer research to operations in real time
    - 50-60 government, academic, & private sector researchers & forecasters participate
- Other Areas of Expertise
    - Forecast and analysis systems
    - Lightning location and detection network

- Cloud physics
- Hydro-meteorological warning systems
- Profiler design
- Data processing and communication
- QA/QC, maintenance, and calibration systems

Participant Discussion of Current And Future Directions for Observations
(The following is an informal list of issues raised by one or more participants during discussion—they do not necessarily reflect the views of the NRC or BASC):

- What exactly is the Hazardous Weather Testbed?
    - Really a grassroots effort, opportunity for modeling and forecasting community to collaborate. Much more organized over the past five years. Every spring, five or six modeling groups + other visitors come together, formulate a daily forecast, critique it, and compare with operational forecasts. Still ad hoc in terms of staff and support.
- Q: Is the latest phased-array data still classified?
  It's old technology>The antenna is not classified nor is any of the work with phased array conducted at NWC.

Final Discussion – Participants Discussion on all Forum Topics
(The following is an informal list of issues raised by one or more participants during and after the meeting—they do not necessarily reflect the views of the NRC or BASC):

- It may be possible that an ensemble system composed of as many as 100 members is not offering a major forecast improvement, or even that the models need a lot of improvement. In terms of prediction--it may just be that more/different/better data for verification are required to improve understanding. For instance, the processing and assimilating radar data could be improved, but this would require a major effort.
- There is some indication that forecast improvements for some types of severe weather phenomena "don't have a lot of headroom" left, that the main area that needs improvement is communication of risk, which is more of a communication problem than a "pure" meteorology problem.
- Communication issue is connected to climate information communication, especially in the context of false alarms.
- The fact that we already have 100+ deaths this year makes this a ripe opportunity for effecting major change, as opposed to incremental improvements.
- If the weather enterprise were re-created from scratch, knowing what we know today, how would we do it?

<u>Abbreviations and Initialisms</u>

4DDA	four-dimensional data assimilation
ABI	advance baseline imager
AIRS	Atmospheric Infrared Sounder
AMSR-E	Advanced Microwave Scanning Radiometer-Earth Observation System
ARRC	Atmospheric Research Center
ATM	Atmospheric Sciences Division

AWIPS	Advanced Weather Interactive Processing System
BASC	Board on Atmospheric Sciences and Climate
CAP	Common Alerting Protocol
CASA	Collaborative and Adaptive Sensing of the Atmosphere
CFS	Climate Forecast System
CMA	Chinese Meteorological Agency
EAS	Digital Emergency Alert System
ECMWF	European Centre for Medium Range Weather Forecasting
EMC	Environmental Modeling Center
ERC	Engineering Research Center
ESMF	Earth System Modeling Framework
ET	extratropical transition
FSI	four-dimensional stormcell investigator
GEO	geostationary Earth orbit
GIFS	Global Interactive Forecasting System
GOES	Geostationary Operational Environmental Satellite (Japan)
GPM	Global Precipitation Measurement (mission)
GPS	Global Positioning System
HES	Hyperspectral Environmental Sensor
HWT	Hazardous Weather Testbed
IPY	International Polar Year
JCSDA	Joint Center for Satellite Data Assimilation
JMA	Japanese Meteorology Agency
JPL	Jet Propulsion Laboratory
LARS	Lower Atmospheric Research Section
MADIS	Meteorological Assimilation Data
MCS	mesoscale convective system
MCV	mesoscale convective vortex
MJO	Madden-Julian Oscillation
MODIS	Moderate Resolution Imaging Spectroradiometer
NAEFS	North American Ensemble Forecasting System
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Protection
NCEP	National Center for Environmental Production
NEDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar Orbiting Environmental Satellite System
NPOESS	National Polar-Orbiting Operational Environmental Satellite System
NPP	Net primary productivity
NRC	National Research Council
NSF	National Science Foundation
NSSL	National Severe Storms Laboratory
NSSTC	National Space Science and Technology Center
NWP	numerical weather prediction
NWS	National Weather Service
O2R	Operations to Research
ONR	Office of Naval Research
OSSE	Observing system Simulations Experiments

PATH	Precipitation and All-Weather Temperature and Humidity
PDM	Physical and Dynamic Meteorology
PI	Principal Investigators
POD	Probability of Detection
QPF	quantitative precipitation forecasting
SA	Service Assesment
SBW	Storm-Based Warnings
SERA	Societal and Economic Research and Application
SIP	Societal Impacts Program
SPC	Storm Prediction Center
SPO	Scientific Program Overview
SPoRT	short-term Prediction Research and Transition Program
SREF	Short Range Ensemble Forecast
SSEF	Scale Ensemble Forecast
THORPEX	The Observing System Research and Predictability Experiment
TIGGE	THORPEX Interactive Ground Global Ensemble
T-PARC	THORPEX Pacific-Asian Regional Campaign
TRMM	Tropical Rainfall Measuring Mission
UARS	Upper Atmospheric Research Section
VORTEX-2	Verification of the Origins of Rotation in Tornadoes
WFO	Weather Forecast Office
WRF	Weather Research and Forecast Model