NWS Science and Technology Roadmap

Tropical Cyclone

Team Composition

- **Dr. Daniel Meléndez, NWS/OST – Co-lead**
- **Dr. Chris Landsea, NHC – Co-lead**
- **Christopher Burr, NHC**
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- **Dr. David Green, NWS/OCCWS**
- **Dr. Sunda Gopalakrishnan, AOML/HRD**
- **Mark Moran, NWS/NCEP**

Vision/Benefits/Impacts

- **Focus Area Team Vision:**

  Finer scale and highly accurate track, intensity and inundation forecasts that trigger appropriate responses resulting in reduced loss of life and economic impacts

- **Benefits**
  - Reducing intensity error by 50% at 24-48 hours will allow emergency managers to prepare for the actual predicted storm intensity instead of one hurricane category stronger
  - A 2007 report from the National Hazards Review states "…forecasting in the late 20th century prevented 66-90% of the hurricane-related deaths in the United States that would have resulted from techniques used in the late 1950s, but it is difficult to demonstrate an effect on property damage."
  - Potential societal savings from reliable hurricane forecasts has been increasing; analysis of hurricane damages from 1900 to 2005 suggests a doubling of economic losses from land-falling hurricanes every ten years

- **Impacts**
  - A 2007 report from the Multihazard Mitigation Council (MMC) of the National Institute of Building Sciences concluded that, "…a dollar spent on mitigation saves society an average of $4."
  - NOAA forecasts, warnings, and the associated responses save approximately **$3 billion** during a typical hurricane season. Two-thirds of this savings is due to fewer hurricane-related deaths, and one-third is due to a reduction in property-related damage as a result of social action and preparedness.
  - NOAA forecasting that minimizes the length of coastline under hurricane warnings saves at least **$640,000 per mile*** in evacuation costs

*Per mile evacuation cost estimates vary from under $100,000 to $1 million.

Goals/Targets
Customer Needs

Goal	Outstanding Issues
Halving of days 1-5 forecast errors in tropical cyclone track and intensity forecasts	• Limited ability to observe tropical cyclones sufficiently for analysis/data assimilation • Computational resources limited • Incomplete understanding of intensity change
Reduce false alarm ratio for rapid intensification (RI) to 10% (Day and 30% (Day 5) Raise probability of detection of RI to 90% (Day and 60% (Day 5)	• Research needed into controlling factors and improved statistical schemes in short-term and greatly improved dynamical models (e.g., Hurricane Forecasting System) • Limits of predictability uncertain
Skillfully track prediction to 7 days for fleet protection and tourism	• Increased operational computing capacity and implementation of HFS/GFS and long-term guidance needed from other models (ECMWF, UKMET, NOGAPS, etc.)
Analyze and provide skillful forecasts of tropical cyclone size (wind radii) out 5 days	• Observations limited for complete analysis of surface wind field • Skill level uncertain from global and hurricane models for tropical cyclone structure
Provide new warning criteria – Storm Surge Watches/Warnings	• Significant education and outreach with public and emergency managers needed

Goals/Targets
Customer Needs

Goal/Target	Outstanding Issues
Provide tropical cyclone track/intensity/size forecasts and warnings for systems before onset	• Increased understanding of tropical cyclogenesis and evolution needed • Enhanced skill in global and hurricane models for genesis
High resolution four-dimensional modeling of tropical cyclones for forecasting track, intensity, and size up to 7 days	• Computation resources limited • Best use of modeling uncertain: single highest resolution deterministic run or multiple slightly lower resolution ensemble runs • Best parameterizations needed for various processes (convection, sea spray, ocean mixing, etc.) uncertain • Optimal mix of observations needed for data assimilation uncertain
Extremely high resolution modeling of tropical cyclone local wind and surge impact guidance for up to 36 hours before landfall	• Computation resources limited • Understanding incomplete on how boundary layer winds change at coastal interface

Key Information Gaps

Gap	Solution Alternative	Impact
1. Uncertain impact of given observations on forecasts	1.1 Capability needed to evaluate value of observations and instruments on forecasts and advise NOAA on investment decisions (Observing System Experiments [OSE] and Observing System Simulation Experiments [OSSE]) 1.2 Field experiments focusing on key physical processes to support model development	• Investment decisions • Model guidance • Observational systems • Uncertainty

Key Information Gaps

Gap	Solution Alternative	Impact
2. Incomplete observations for analyses and data assimilation needs	2.1 Equip all 10 Air Force WC-130 aircraft with Doppler radar 2.2 Geostationary Doppler-in-space/geostationary microwave sounder 2.3 Next generation QuikSCAT – Dual Frequency Scatterometer aboard Japanese satellite in short term, Extended Ocean Vector Winds Mission (XOVWM) in long term 2.4 Low-altitude (e.g., Aerosonde) and high-altitude (e.g., Global Hawk) unmanned aircraft	• Investment decisions • Model guidance • Observational systems • Analysis capabilities
3. Tropical cyclone track/intensity/size prediction before onset	3.1 High-resolution mesoscale and cloud-scale ensemble models assimilating radar and other data (e.g., HFS/GFS) 3.2 Advanced radar and satellite data assimilation 3.3 Increase high-performance computing capacity and capability 3.4 National Hurricane Forecast System (NHFS, IOC 2013)	• Model guidance • Performance • Uncertainty

Key Information Gaps

Gap	Solution Alternative	Impact
4. Physical understanding of genesis, intensity and structure change incomplete	4.1 Yearly hurricane field program with interagency collaborations to leverage resources 4.2 Focus on basic and applied research on tropical cyclones within NOAA laboratories	• Investment decisions • Performance
5. Extremely high resolution modeling of tropical cyclone local wind and surge impact guidance for up to 36 hours before landfall	5.1 Develop extremely high res hurricane model (~ 100 m) for impact prediction at and during landfall 5.2 Develop next generation hydrodynamic (storm surge and inundation) operational model (with the NOAA Storm Surge Transition Project) 5.3 Storm-surge testbed	• Forecast guidance • Performance • Uncertainty • R2O rate

Key Information Gaps

Gap	Solution Alternative	Impact
6. Predictability limits of size, track, intensity, genesis, and structure as function of lead time	6.1 Study predictability of genesis at various lead times via both POD and FAR 6.2 Fund predictability studies at DTC	• Performance • Investment decisions • Model guidance • Uncertainty • Reliability
7. Observational and forecast guidance uncertainty	7.1 Build multi-model ensemble system with high quality numerical guidance collected from leading numerical prediction centers, including high resolution control and ensemble suite runs 7.2 Statistical post-processing, bias correction, and downscaling from global to regional to local scales 7.3 Develop high-resolution (ca. 1-km) hurricane ensembles to quantify uncertainty 7.4 “Most-probable forecasts” from a derived probability density function representing total forecast error (managed diversity)	• Uncertainty • Model guidance

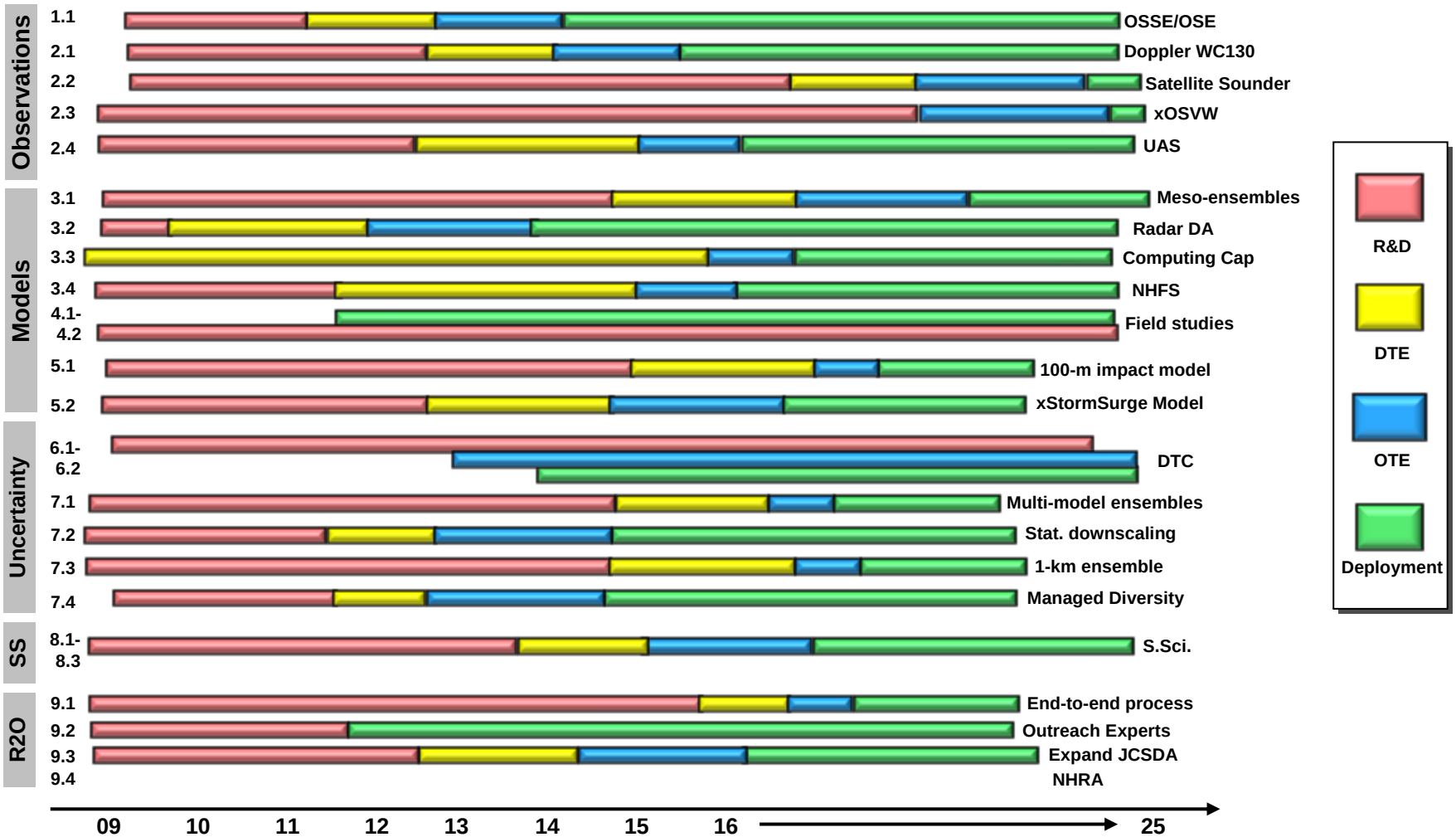
Key Information Gaps

Gap	Solution Alternative	Impact
8. Societal factors – public understanding and communication	8.1 Integration of social science into NWS training and operations 8.2 Targeted social research on how public uses warning information 8.3 Integration of decision support systems into NWS operations	• Investment decisions • Decision support
9. R2O rate insufficient to sustain goal	9.1 Establish an end-to-end process to transition new observing systems and platforms and modeling improvements into operations 9.2 Expand JCSDA scope to support HFS and GFS improvements beyond just satellite data impact 9.3 Broaden expertise of operational tropical cyclone operational numerical prediction and research communities and broaden access to R&D community 9.4 National Hurricane R&D Alliance 9.5 National Hurricane Testbed	• Investment decisions • R2O rate • Performance • Outreach

Research Needs and Opportunities

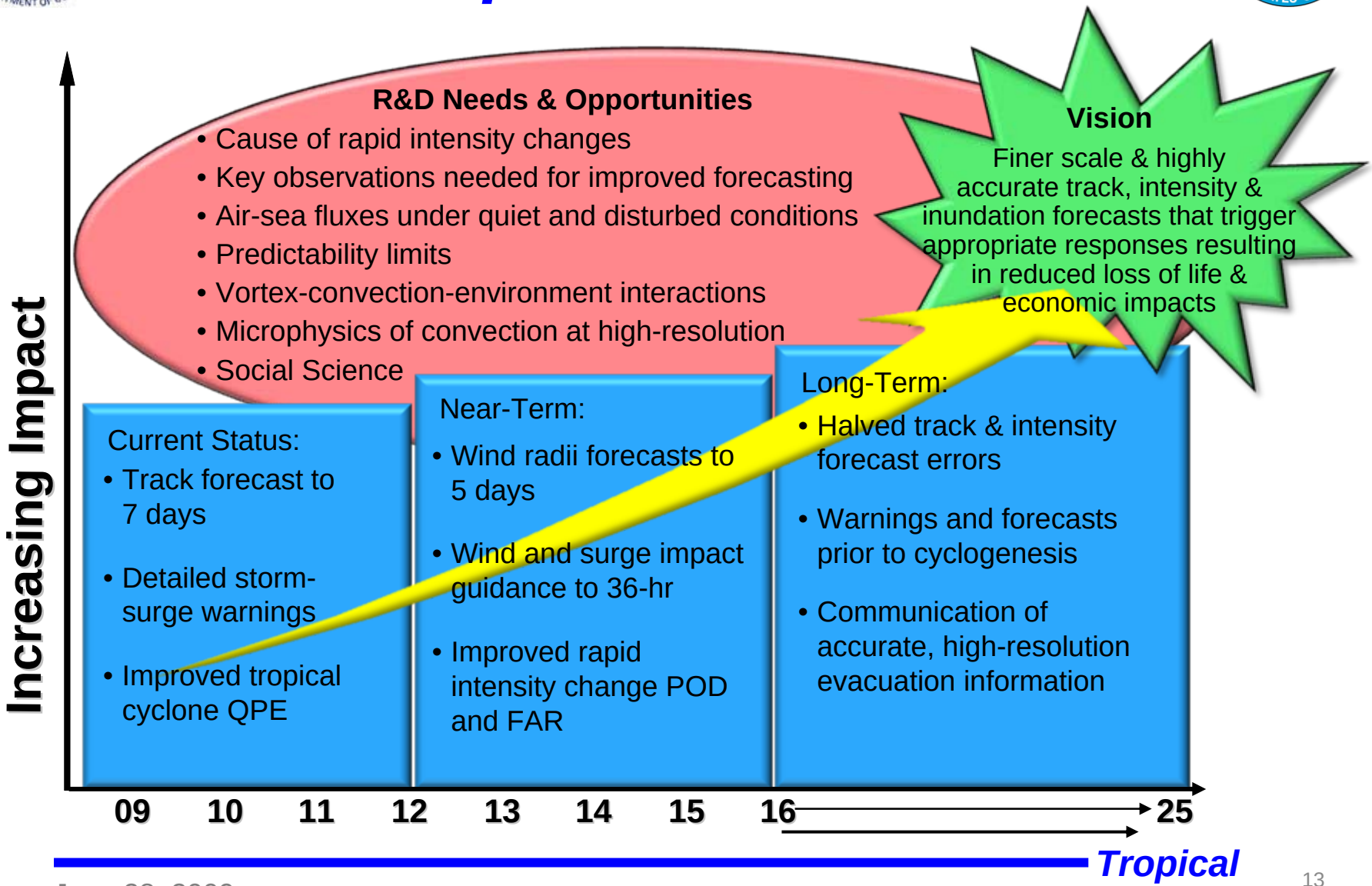
- **Short-term**
  - Investigate causes of rapid intensity changes in tropical cyclones: development of vigorous convection in the presence of the enhanced storm circulation; development under very low shear and high moisture and instability levels
  - Investigate eyewall replacement cycle forcing
  - Determine key observations needed for optimal track, intensity, size, structure, and genesis forecasting
  - Radar data (and other inner core observations) assimilation into hurricane NWP Radar data assimilation into tropical cyclone NWP
  - Air-Sea Interaction (oceanic/atmosphere boundary layer): Air-Sea fluxes (exchange coefficients) under disturbed conditions (e.g., sea spray)
- **Long-term**
  - Predictability limits as a function of lead time for genesis, track, size and intensity forecasts
  - Environmental forcing (“good” vs. “bad” trough interactions)
  - Convective Scale processes: organization of convection (eyewall vs. stratiform); feedback between vortex, core, and environment; convective physics and environment
  - Microphysics of convection at high-resolution; liquid vs. ice
- **Additional outstanding research needed**
  - Inner Core Region feedback between vortex, convection, and environment
  - Turbulence and subgrid scale missing: upper ocean processes (depth of mixed layer, representation of oceanic circulations)

Alternative Solutions - Tropical



Tropical

Focus Area Team Summary: Tropical Weather



Target Performance Measures: Tropical

Proposed	Current (2009)	FY 2016 Target Example	FY 2025 Target Example
Track error reduction rate	-1.5% / year	-20% cumulative	-50% cumulative
Intensity error reduction rate	-0.8% / year	-20% cumulative	-50% cumulative
Rapid Intensity POD at day 1	30%	60%	90%
Rapid Intensity POD at day 5	0%	30%	60%
Rapid Intensity FAR at day 1	80%	40%	10%
Rapid Intensity FAR at day 5	100%	65%	30%
Track forecasts to day 6	---	275 nm average error	200 nm average error
Track forecasts to day 7	---	350 nm average error	250 nm average error
Analyze and forecast surface wind field	Hurricane wind radii to 36 hr	Hurricane wind radii to 3 days	Hurricane wind radii to 5 days
Provide track/intensity/size forecasts before genesis	---	---	500-m resolution 3 kt accuracy

Target Performance Measures: Tropical

Proposed	Current (2009)	FY 2016 Target Example	FY 2025 Target Example
Issue Storm Surge Watches/Warnings	---	20 min leadtime	1 hr leadtime
High res forecast model out through 7 days	---	Init Operating Capability	500-m
Extremely high res impact forecast model out through 36 hr	---	---	50-m
Pre-genetic forecast skill	Climatology	Better than chance	Better than baseline model