# Airborne Platform Requirements for Advancing Dynamics and Physics of Weather Forecasts

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# My Experience

Field projects

- ocean, land, tropics, midlatitudes, mountains
- convection, tropical cyclones, fronts, orographic precipitation

A/C used

- P3s, Electra, DC-8, Citation, ER-2, Global Hawk, + others

Satellites

- TRMM, GPM, CloudSat

# The Aircraft I have used


NCAR Electra


NOAA P3


NASA DC-8


NASA ER-2


NASA Global Hawk


North Dakota Citation

# Questions Regarding NASA Airborne Platforms to Advance Earth Science

- What emerging science/research questions can be best addressed **with large platforms** as the airborne component for the integrated studies?
- Which of these science questions might be well-suited to combinations of **smaller platforms** for their airborne component should a large platform not be available? What is the loss to science if the airborne component needed to be done through a combination of one or more smaller-sized aircraft?
- How might newly available suborbital platforms (especially **UASs** and advanced technology balloons) similarly contribute to integrated studies addressing these scientific questions?

# Aircraft Required for High-impact Weather Systems

# Weather systems producing precipitation and severe weather

Large convective clouds
Mesoscale convective systems (MCSs)
Tropical cyclones
Frontal cloud systems

# Outstanding questions affecting precise prediction of weather systems producing precipitation and severe weather:

What factors determine sizes and lifetimes of storms?

How are mesoscale motions induced within storms?

What factors control the microphysical growth and fallout of precipitation particles?

How do aerosols affect the structures and intensities of predicted storms?

→ Need comprehensive observations of weather systems to test prediction accuracy

# Scales of Weather Systems

| Weather Phenomenon | Height Scale | Horizontal Scale | Time Scale |
|---|---|---|---|
| Convective cloud | 10-15 km | 10s of km | Hours<br>Evolving ~ minutes |
| MCS | 10-15 km | 100s of km | *10s of hours,*<br>evolving ~ 1-10 minutes |
| Eyewall/rainband | 10-15 km | 100s of km | 10s of hours → day<br>evolving ~ 1-10s of minutes |
| Frontal system | 10-15 km | 10-1000 km | 1-10 hours<br>Evolving, 10s of minutes |

Altitude range
1-15+ km

Flight duration
~10 hours

# Types of *in situ* measurements required

- T, p
- Water vapor—problematic but critical
- u, v
- w—very problematic, only can get extremes
- Drop size
- Ice particle types, sizes, and concentrations
  - Ice crystal habits
  - Aggregates (snow)
  - Graupel
  - Hail

Simultaneous in-cloud sampling

→ Robust A/C for icing, hail, lightning, turbulence

# Types of remote sensing measurements required

Targeting—

- On board radar
- Ground-based radar
- Satellite imagery

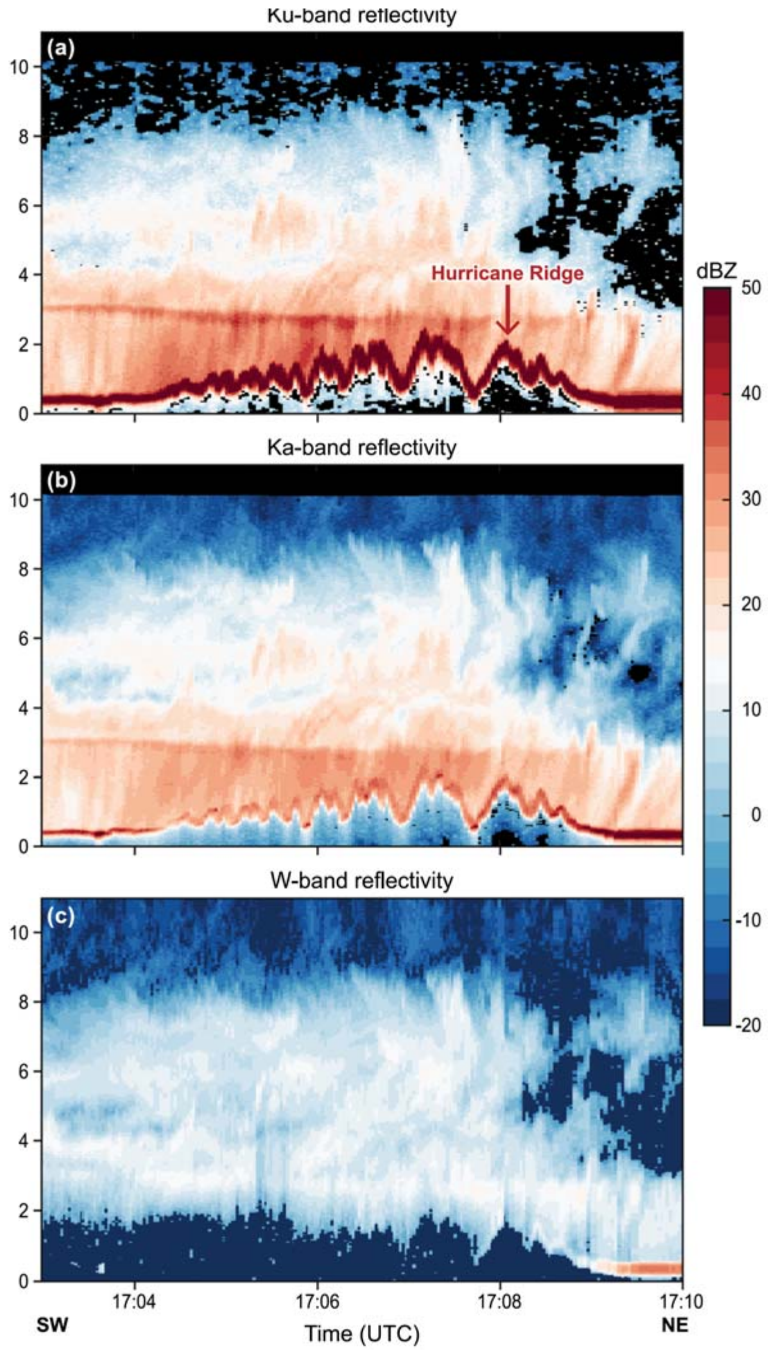
Spatial distributions—

- Precipitation particles (X, Ku, Ka band radars)
- Cloud particles (W band radar)
- Wind components (u, v, w Doppler radar)
- Particle types (dual-polarized radar)

Payload sufficient for radars

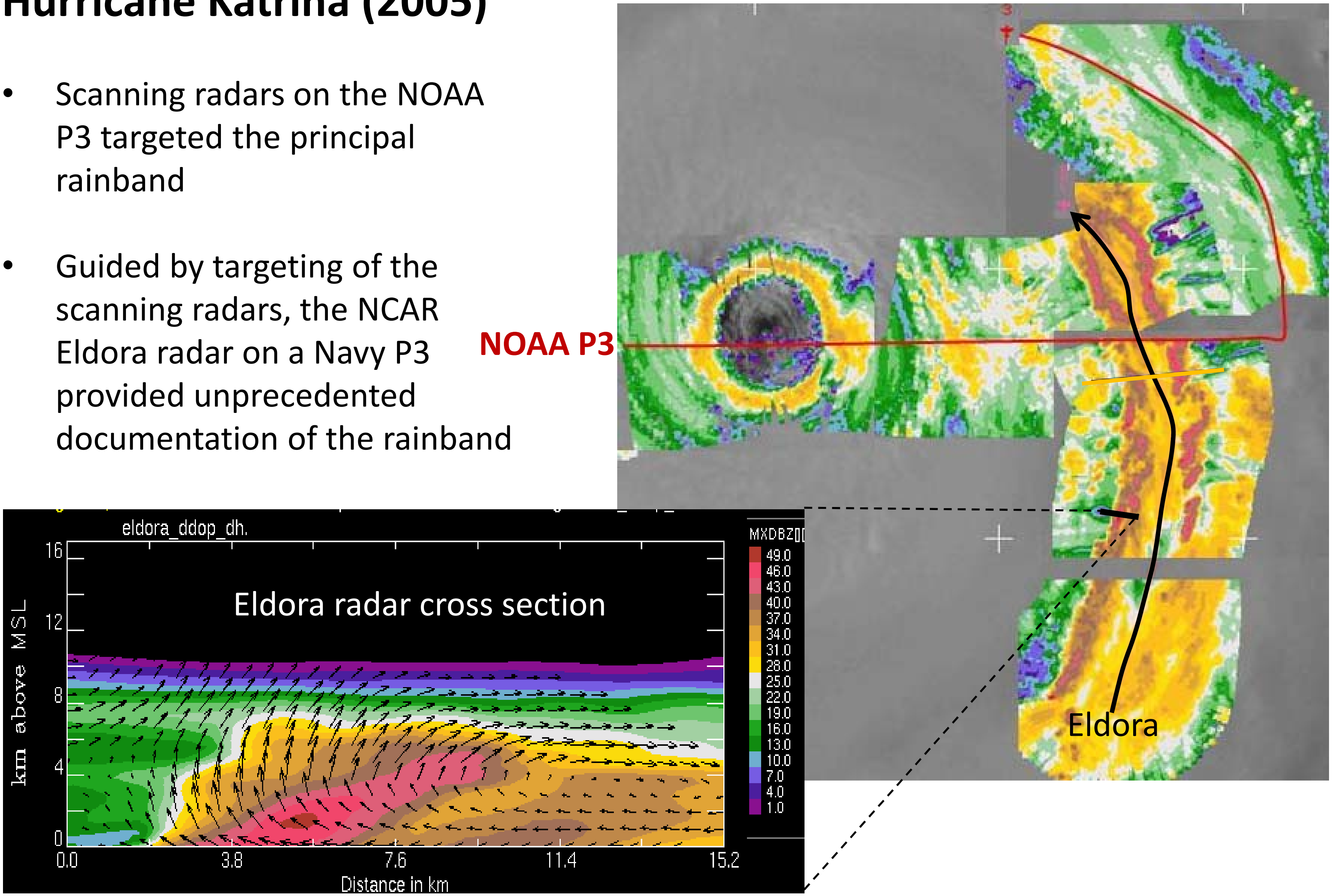
# DC-8 flight with APR3 radar over the Olympic Mountains in OLYMPEX in 2015

- Three different radar frequencies used to show how mountains affected the frontal storm
- Provided context for smaller citation aircraft to sample microphysics at different altitudes



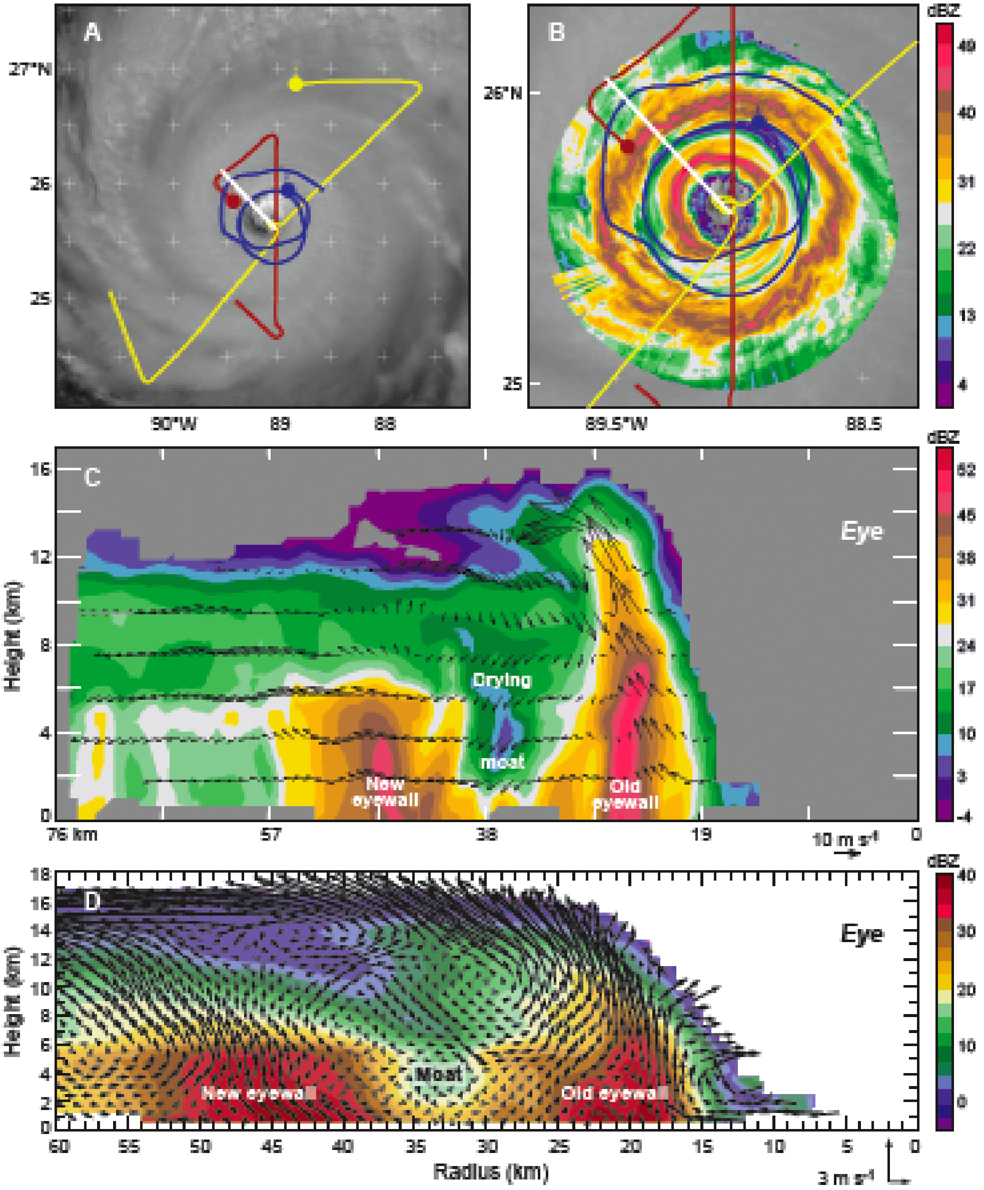
# Two P3s flying in Hurricane Katrina (2005)

- Scanning radars on the NOAA P3 targeted the principal rainband
- Guided by targeting of the scanning radars, the NCAR Eldora radar on a Navy P3 provided unprecedented documentation of the rainband



# Three P3s flying in Hurricane Rita during eyewall replacement

- Scanning radars on the NOAA P3s targeted the eyewall replacement
- Guided by targeting of the scanning radars, the NCAR Eldora radar on a Navy P3 provided unprecedented documentation of the eywall replacement



## Types of environmental measurements required

Dropsondes

Aerosol sampling

Lidar for aerosol spatial distribution and concentration

Lidar for environmental air motions

Boundary layer T, water vapor, turbulence

Payload sufficient
for lidars & aerosol
sampling

# Summary for High-Impact Weather Aircraft

**Types of research aircraft required for high-impact weather systems**

- Long duration (~10 hour flights)
- Wide range of altitude capability (up to at least 15 km)
- Robust airframe (flying in icing and turbulent conditions)
- Payload capable of handling radars and lidars

**Important supplementary roles for smaller aircraft**

- Penetration of very intense updrafts and downdrafts
- Sampling of hail
- Sampling of environmental aerosol
- Sampling of sub-cloud layer phenomena (e.g., cold pools)

# Aircraft Required for Boundary-layer Weather Events

# Boundary-layer phenomena challenges in weather prediction

- Large oceanic stratus fields
- Arctic stratus
- Fog episodes
- Aerosol concentration and types
- Sub-cloud layer turbulence in areas of convective clouds
- Sea-spray and turbulence in tropical cyclones
- Air pollution events

# Aircraft requirements for boundary layer weather phenomena

- Altitude
  - Only about 1-2 km
- Flight duration
  - Large range required, ~10 hour flights
- Payload
  - Radiation measurement
  - Turbulence
  - Radar
  - Lidar
  - Cloud microphysical sampling
  - Aerosol sampling—type, concentrations
- Potentially harsh flight conditions
  - Possible icing in some situations
  - Turbulence in tropical cyclone boundary layer

# Summary for Boundary-layer Weather Aircraft

**Types of research aircraft <u>required</u> for boundary-layer weather systems**

- Long duration (~10 hour flights)
- Robust airframe (flying in icing and turbulent conditions)
- Payload capable of handling radars and lidars
- Low-altitude flying

**Important supplementary roles for smaller aircraft or UASs**

- Radiation
- Profiling of T and water vapor

## Take Home Message from RAH

Large A/C are necessary for duration, altitude, targeting, and payload requirements

Smaller A/C are important for supplementary roles

# Discussion Topics

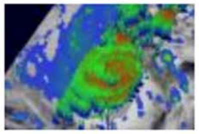
- How best to do targeting to optimize measurements
- Should NASA think of large a/c for remote sensing and smaller a/c for:
  - Low level boundary layer sampling
  - Penetration of upper level clouds for microphysics and vertical velocity measurement

# WAD Research Questions

Weather and Atmospheric Dynamics addresses the following overarching questions:

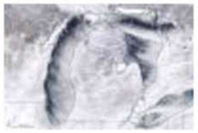
How can sub-seasonal to seasonal weather forecast duration and reliability be improved?

How can we improve predictive capability for weather, including extreme events?



What is the role of deep convective towers and precipitation on a tropical storm's life cycle?

To what extent are storm intensification processes predictable?



How can we use NASA, NOAA and other countries' satellite observations innovatively and transition new algortithms, data, and tools to weather forecast operations at our partner agencies?

**TABLE 7.1** Summary of Science and Applications Questions and Their Priorities

| Science and Applications Questions | | Highest Priority Measurement Objectives (MI–Most Important, VI–Very Important) |
|---|---|---|
| ***W-1*** | What planetary boundary layer (PBL) processes are integral to the air-surface (land, ocean, and sea ice) exchanges of energy, momentum, and mass, and how do these impact weather forecasts and air quality simulations? | **(MI) W-1a.** Determine the effects of key boundary layer processes on weather, hydrological, and air quality forecasts at minutes to subseasonal time scales. |
| ***W-2*** | How can environmental predictions of weather and air quality be extended to seamlessly forecast Earth system conditions at lead times of 1 week to 2 months? | **(MI) W-2a.** Improve the observed and modeled representation of natural, low-frequency modes of weather/climate variability (e.g., MJO, ENSO), including upscale interactions between the large-scale circulation and organization of convection and slowly varying boundary processes to extend the lead time of useful prediction skills by 50% for forecast times of 1 week to 2 months. |
| ***W-3*** | How do spatial variations in surface characteristics (influencing ocean and atmospheric dynamics, thermal inertia, and water) modify transfer between domains (air, ocean, land, cryosphere) and thereby influence weather and air quality? | **(VI) W-3a.** Determine how spatial variability in surface characteristics modifies regional cycles of energy, water, and momentum (stress) to an accuracy of 10 W/m$^2$ in the enthalpy flux, and 0.1 N/m$^2$ in stress, and observe total precipitation to an average accuracy of 15% over oceans and/or 25% over land and ice surfaces averaged over a 100 × 100 km region and 2- to 3-day time period. |
| ***W-4*** | Why do convective storms, heavy precipitation, and clouds occur exactly when and where they do? | **(MI) W-4a.** Measure the vertical motion within deep convection to within 1 m/s and heavy precipitation rates to within 1 mm/hour to improve model representation of extreme precipitation and to determine convective transport and redistribution of mass, moisture, momentum, and chemical species. |
| ***W-5*** | What processes determine the spatiotemporal structure of important air pollutants and their concomitant adverse impact on human health, agriculture, and ecosystems? | **(MI) W-5a.** Improve the understanding of the processes that determine air pollution distributions and aid estimation of global air pollution impacts on human health and ecosystems by reducing uncertainty to <10% of vertically resolved tropospheric fields (including surface concentrations) of speciated particulate matter (PM), ozone ($O_3$), and nitrogen dioxide ($NO_2$). |
| ***W-6*** | What processes determine the long-term variations and trends in air pollution and their subsequent long-term recurring and cumulative impacts on human health, agriculture, and ecosystems? | The objective associated with this question was ranked Important. See subsequent sections for details. |
| ***W-7*** | What processes determine observed tropospheric ozone ($O_3$) variations and trends, and what are the concomitant impacts of these changes on atmospheric composition/chemistry and climate? | The objective associated with this question was ranked Important. See subsequent sections for details. |
| ***W-8*** | What processes determine observed atmospheric methane ($CH_4$) variations and trends, and what are the subsequent impacts of these changes on atmospheric composition/chemistry and climate? | The objective associated with this question was ranked Important. See subsequent sections for details. |
| ***W-9*** | What processes determine cloud microphysical properties and their connections to aerosols and precipitation? | The objective associated with this question was ranked Important. See subsequent sections for details. |
| ***W-10*** | How do clouds affect the radiative forcing at the surface and contribute to predictability on time scales from minutes to subseasonal? | The objective associated with this question was ranked Important. See subsequent sections for details. |