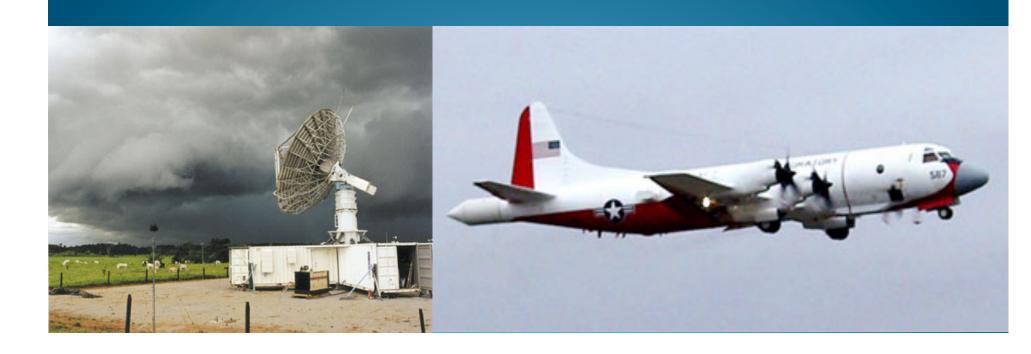
### Emerging science frontiers requiring radar facilities

### Bob Rauber

University of Illinois at Urbana-Champaign



### Central questions of this workshop

During the next 10-20 years...

- 1. What emerging science frontiers will require field research using advanced radar systems?
- 2. What technologies are required to make the necessary measurements with these radar systems?
- 3. How should the radar facilities available to the research community be structured and funded to meet these demands?

### **Emerging Science Frontiers**

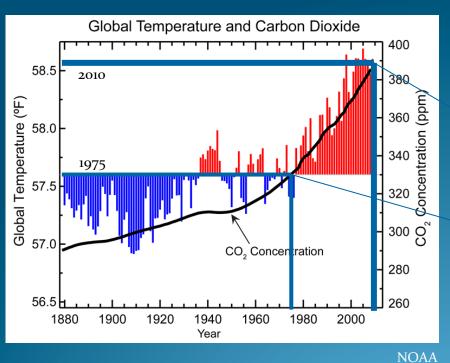
Research must have relevance......

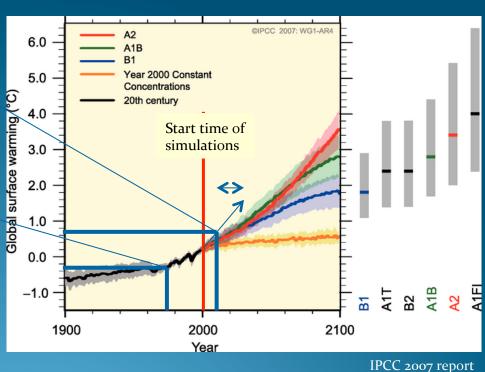
- 1. Address national and global needs of 21st century society
- 2. Contribute to advances within and beyond the atmospheric sciences
- 3. Develop a better understanding of, and response to natural hazards, particularly extreme events
- 4. Be a key component of multi-platform, multi-model investigations of meteorological phenomena



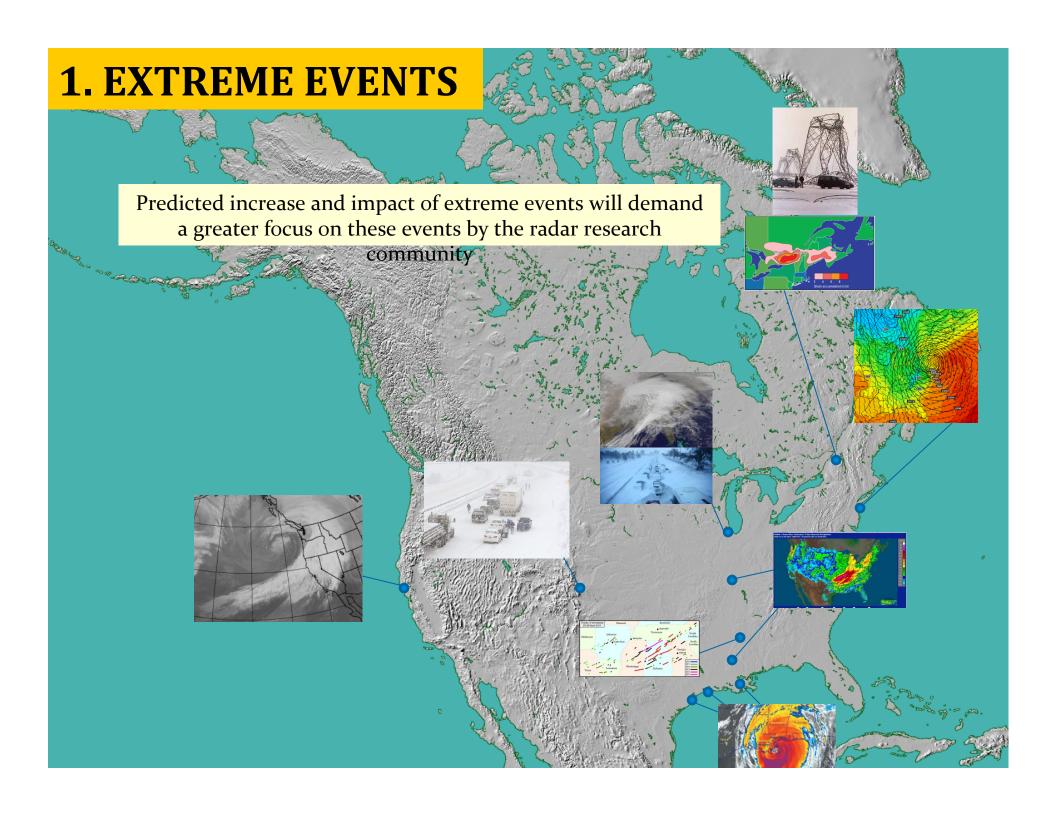
### Environmental context

The next two decades will be the time period where global climate change <u>impacts</u> will progressively drive scientific research



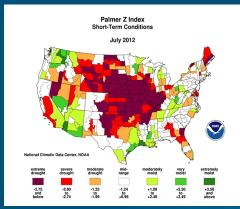


### Four major themes of this talk

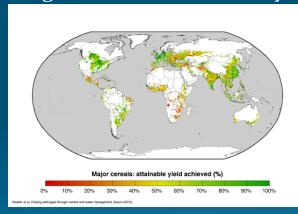


### 2. HYDROLOGY/WATER RESOURCES

### Water demands



### **Agricultural Productivity**



### Flooding



### Availability of clean, fresh water

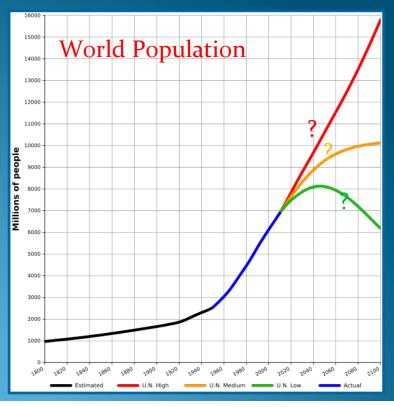




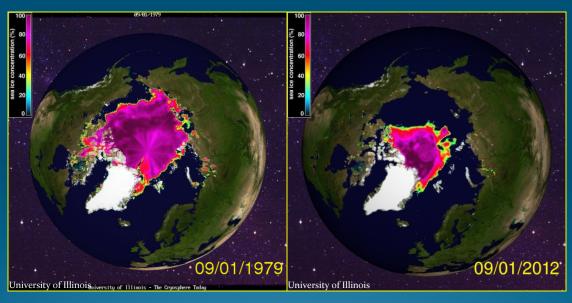
Mountain Glacier decline

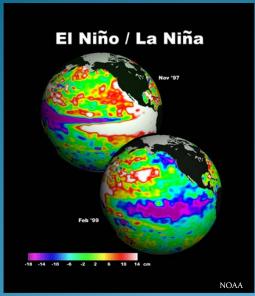


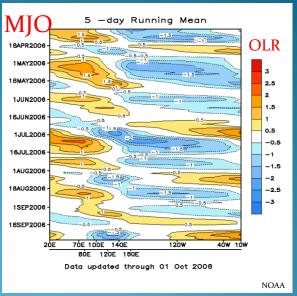




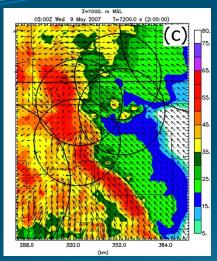
### 3. GLOBAL CLIMATE/CLIMATE CHANGE







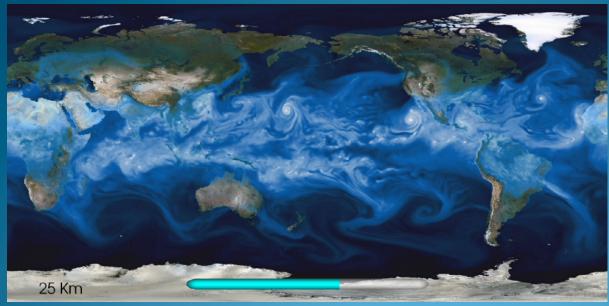
### 4. INTEGRATION WITH MODELING



Snook et al.. Mon. Wea. Rev., 139, 3446-3468.

Assimilation of radar data into mesoscale and forecast models will achieve greater levels of sophistication

Initialization and verification of numerical simulations

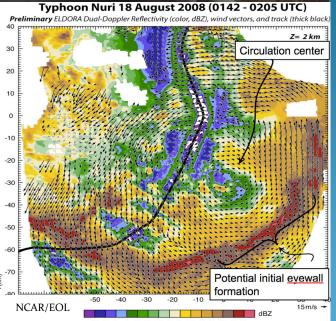


Wehner et al. 2011: Courtesy of Lawrence Berkley National Lab, Univ of Michigan, and NCAR

Global Climate Models will resolve mesoscale circulations observable with radar Emerging Science Frontiers

EXTREME EVENTS

# TRMM/NASA



### Tropical cyclone research

### <u>Tropical cyclone genesis, structure, and rapid intensification</u>

- Dual wavelength radar (Ka-W) for cloud microphysics, airflow, ocean winds
- Next generation airborne dual Doppler for winds (Possibilities: phased array, dual polarization, deployable on high performance or storm penetrating aircraft)
- Clear air Doppler lidar for environmental winds, clouds, and aerosols

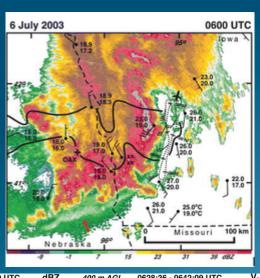
### Landfall

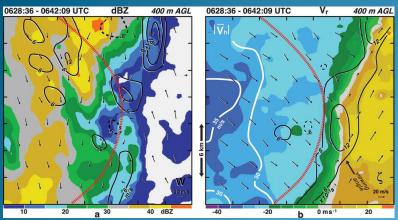
- Mobile, high resolution, rapid response dual-pol Doppler radar networks for meso-α flow structure, microphysics, and precipitation over a broad area
- Doppler, dual-wavelength profilers for vertical air motion and precipitation microphysics

### Convective weather systems

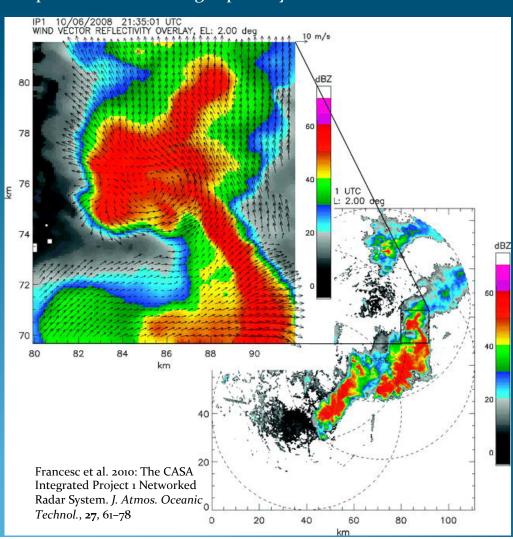
Rapidly evolving convective weather systems with extreme boundary layer winds (supercells, tornadoes, MCS gust front boundaries, sharp fronts)

Need for focused radar networks capable of providing boundary layer coverage with rapid volume scanning capability





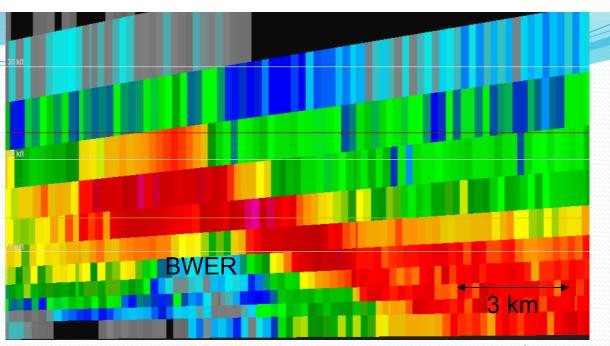
Wakimoto et al., 2006: High Winds Generated by Bow Echoes. Part I and II: Mon. Wea. Rev., 134,



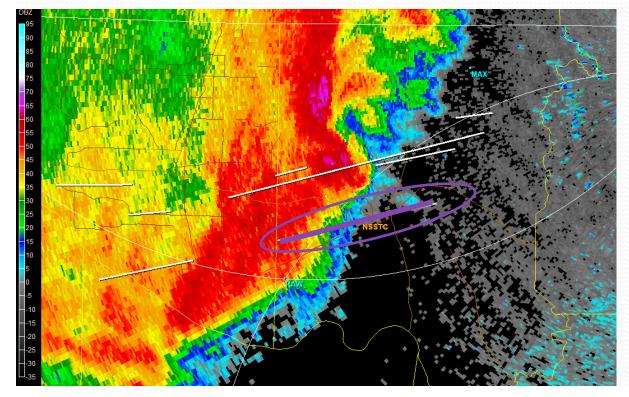
### **Profiling radars**

needed to push science frontiers regarding extreme events

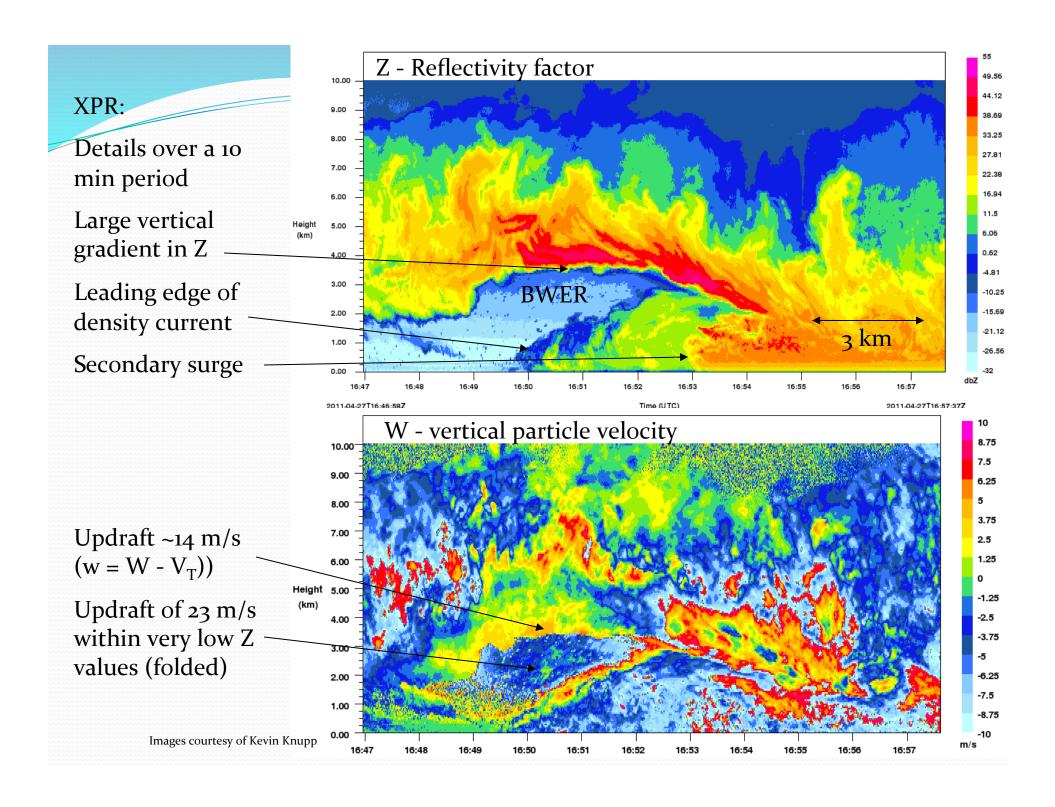
### **Cross-section KHTX 88D**



Images courtesy of Kevin Knupp



BWER is evident but other complex features difficult to identify from KHTX cross-section



### Winter weather systems

Microphysics and dynamics of the rain-snow transition and cloud structure with application to extreme ice storms and heavy snowstorms

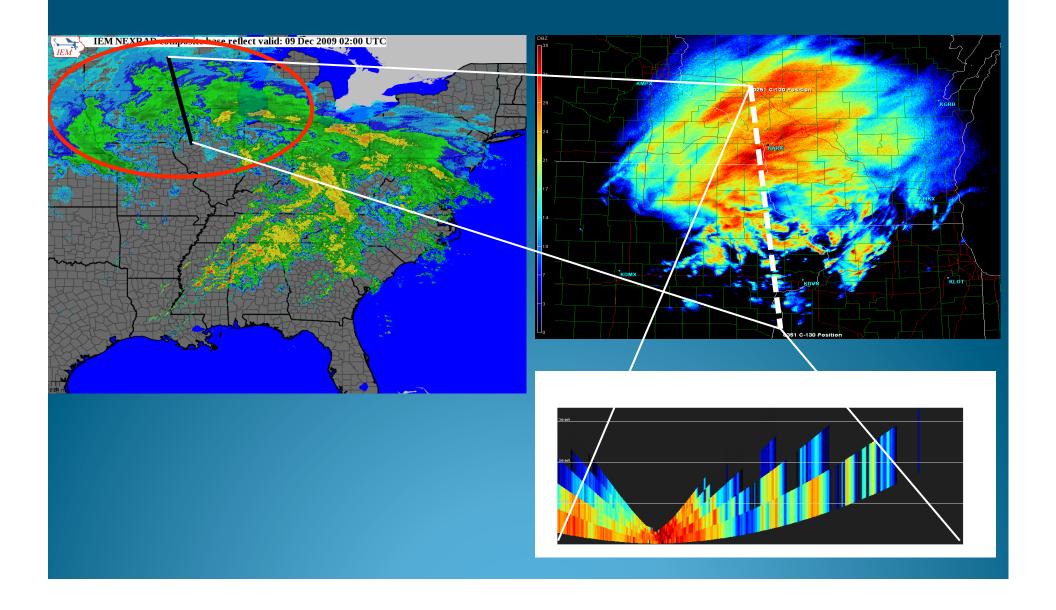


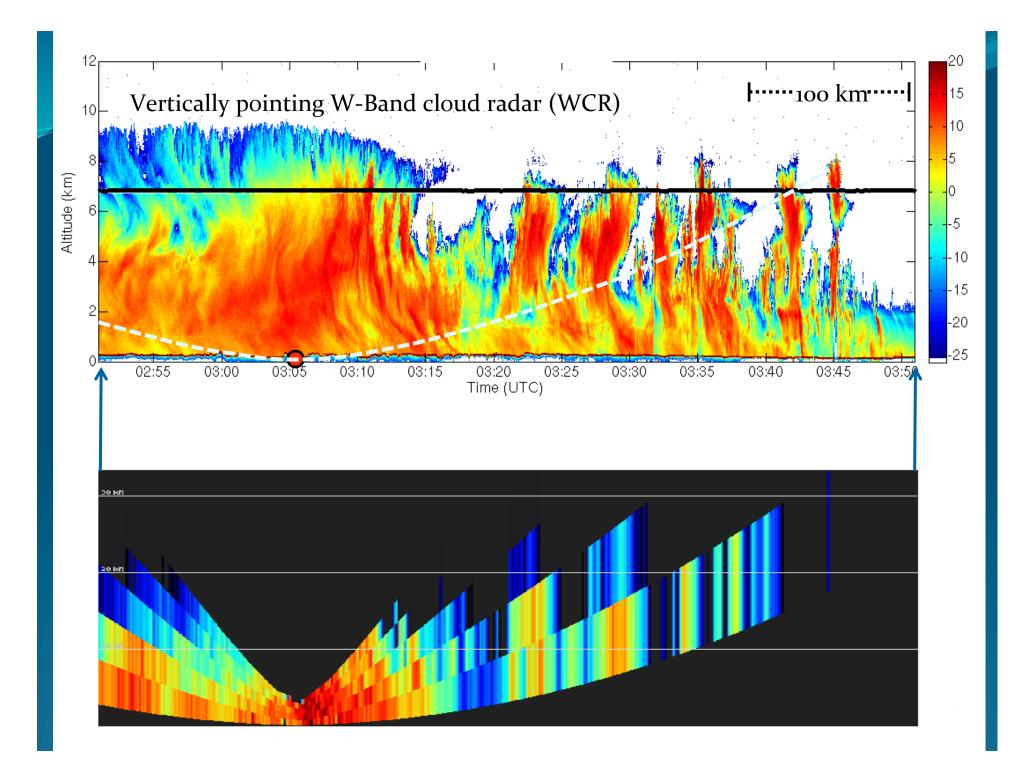




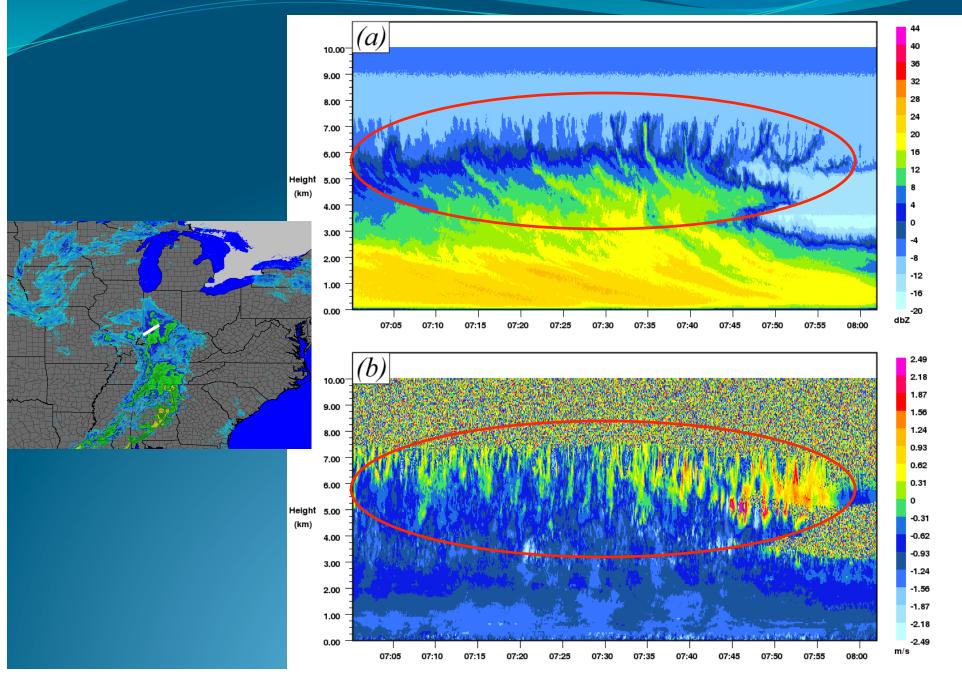


### Radar studies of the organization, mesoscale dynamics and microphysics of cyclones



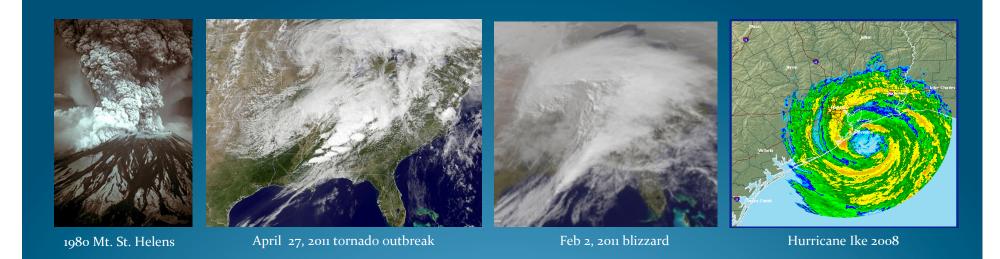


### Processes near cloud top are not well observed with operational or scanning radars



### Rapid response capability for extreme events

The funding system and most radar facilities are not currently designed to deploy assets on extreme events, although many are predictable days in advance, or occur over several days



These are economically important, societally relevant, and scientifically challenging events

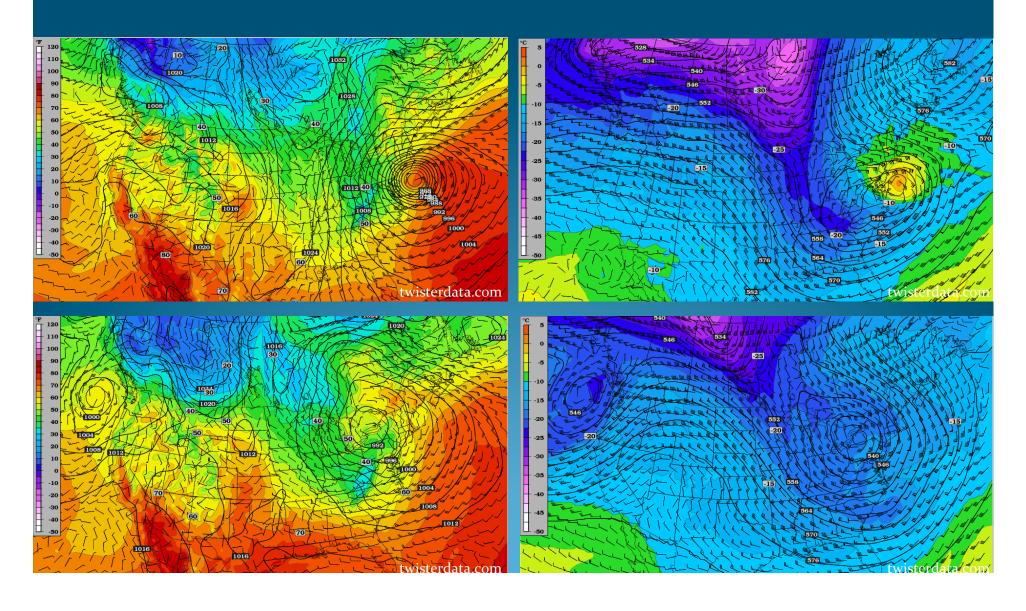
**Emerging Science Frontiers** 

Water Resources
Hydrologic/precipitation processes

Too much water......

### Tropical-extratropical transition

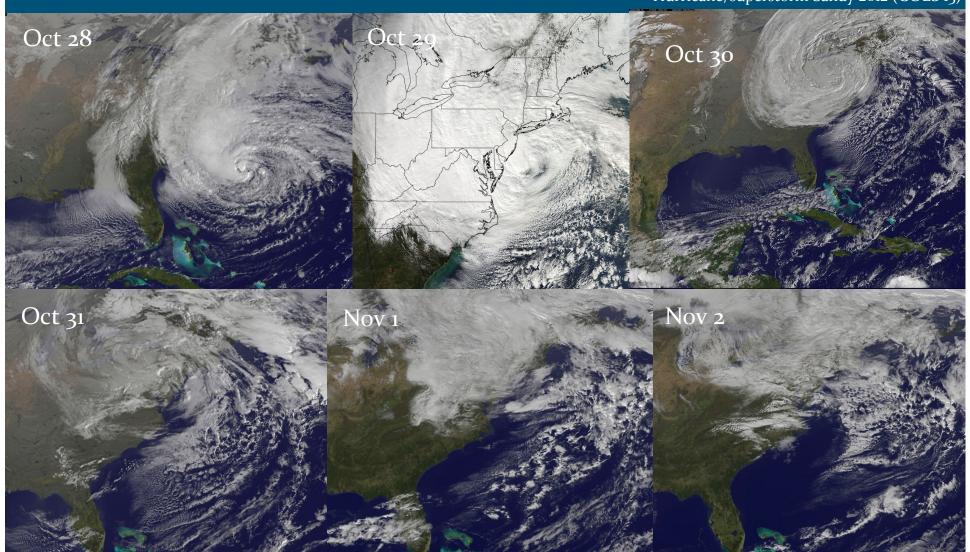
Physical structure, mesoscale dynamics, and microphysical processes associated with the tropical to extratropical transition of landfalling tropical cyclones



### Tropical-extratropical transition

Need for radar investigations during tropical-extratropical transition

Hurricane/superstorm Sandy 2012 (GOES 13)

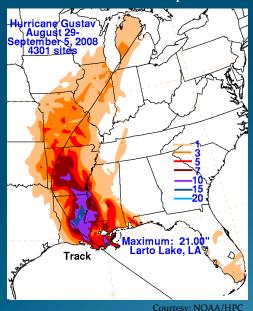


### **Tropical systems**

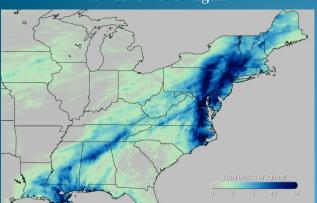
### Societal importance: extreme precipitation in tropical cyclones after landfall

(radar research required for precipitation estimation and flooding)

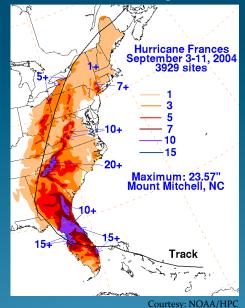
### Hurricane Gustav Sept 2008



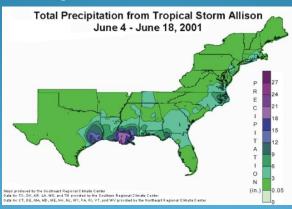
Hurricane Irene August 2011



Hurricane Francis Sept 2004



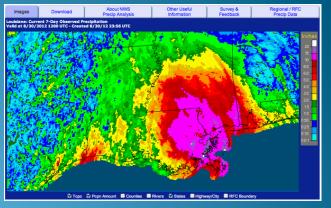
Tropical Storm Allison June 2001



>60 percent of U.S. hurricane deaths from 1970-1999 in U.S. occurred in inland counties

>50% of tropical cyclone deaths in U.S. related to freshwater flooding

### Hurricane Isaac August 23-30 2012



Courtesy: NOAA

Courtesy: Southeast regional climate center

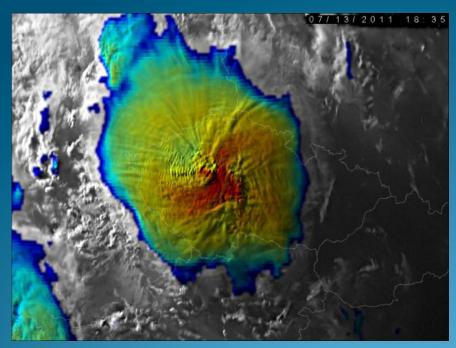
Courtesy: NOAA

### Mid-latitude convective systems

### Heavy convective rainfall and flooding events

### **Nocturnal MCSs**

dynamical mechanisms that initiate, organize and maintain nocturnal convection, coupling of these mechanisms to microphysics, and relationship to heavy rainfall



Story (Fig.)

Ames Cy

Dishories

Cincoln

Copela Ransas City

Fearing

Chita

Cardesville

Stillwater

Tolias

Frycteville

Jonesboro

http://oiswww.eumetsat.org/WEBOPS/iotm/iotm/2010713\_convection/20110713\_convection.html

Weathertap.com

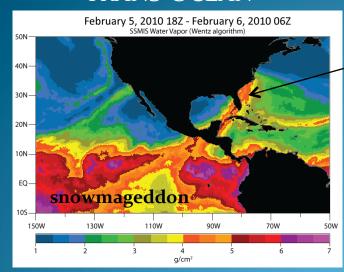
### Atmospheric Rivers, Coastal flooding, and interactions with topography

### ATLANTIC OCEAN

## MIMIC Total Precipitable Water product

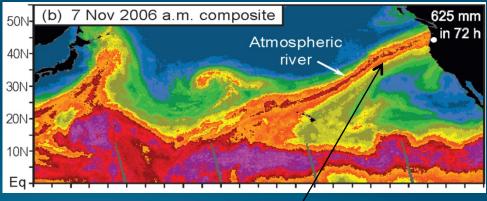
http://cimss.ssec.wisc.edu/goes/blog/archives/3838

### TRANS-OCEAN



http://www.esrl.noaa.gov/psd/atmrivers/events/

### PACIFIC OCEAN



http://www.esrl.noaa.gov/psd/atmrivers/questions

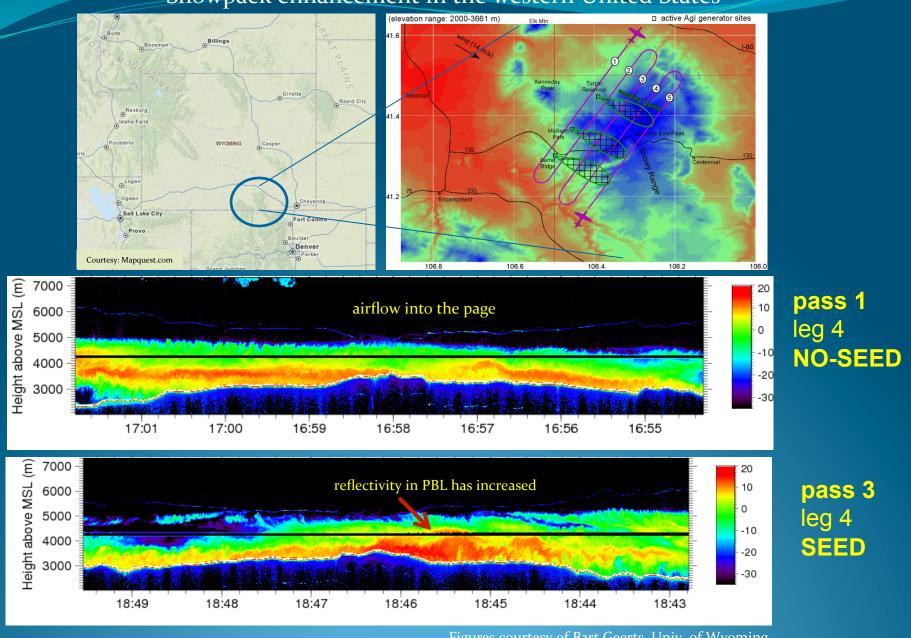
### atmospheric river

- -- "The moisture flux in a typical tropospheric river is ...similar to the flux in the Amazon River"
- -- "carry essentially the total meridional transport observed in the extratropical atmosphere but may occupy only about 10% of the total longitudinal length at a given latitude"

(Zhu and Newell, 1998: Mon. Wea. Rev., 126, 725-735)

Not enough water.....

### Weather modification research Snowpack enhancement in the western United States



Figures courtesy of Bart Geerts, Univ. of Wyoming

How much water.....

### Continuing challenge for radar research: mapping of the water vapor field

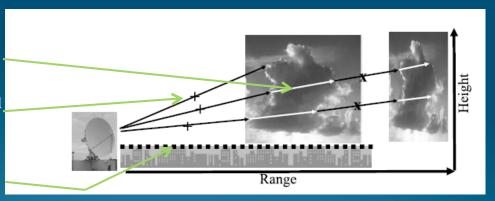
"lack of detailed, high-resolution water vapor measurement in the atmospheric boundary layer is one of the primary limiting factors in being able to predict the timing and location of convection initiation and to produce accurate quantitative precipitation forecasts (QPF)" (Roberts et al, 2008 *Bull. Amer. Meteor. Soc.*, **89**, 1535–1548)

### Water vapor retrieval

Triple Wavelength within cloud (Meneghini et al 2005)

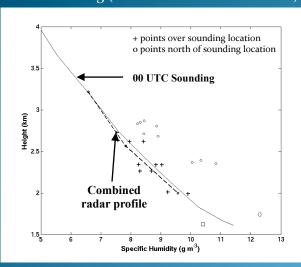
Dual Wavelength outside cloud (Ellis and Vivekanandan 2010)

Boundary layer: Refractivity (Fabry 2004)

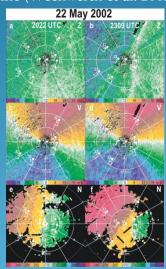


Courtesy of Scott Ellis, NCAR, and Radio Science

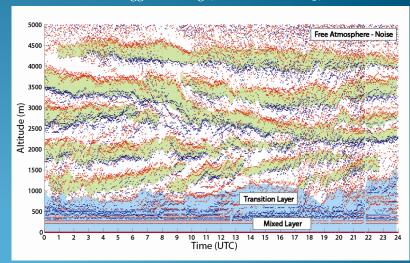
Comparison of retrieved water vapor profile with sounding (Ellis and Vivekanandan 2010)



Radar refractivity along dry line (Weckwerth et al. 2002)



24 hour mapping of moisture layers over tropical Atlantic using Bragg scattering (Davison et al. 2013)



### Radar estimation of snowfall rates, accumulated snowfall, accumulated icing and equivalent liquid precipitation







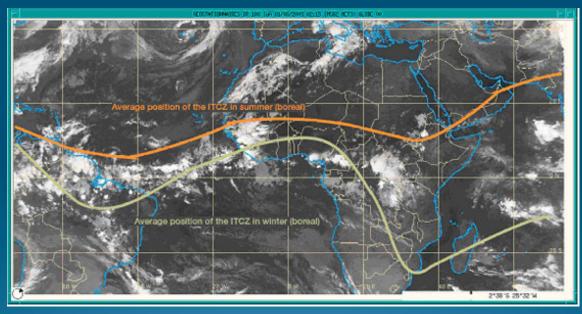
Eric Peterson, Wikipedia Commons

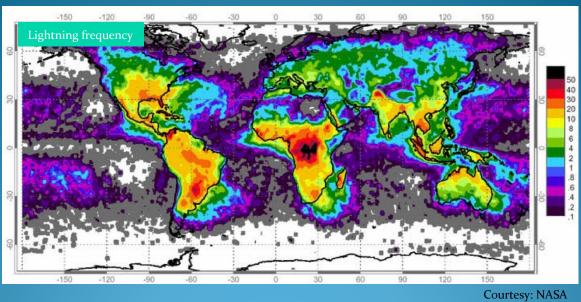
**Emerging Science Frontiers** 

Climate/Climate Change Research

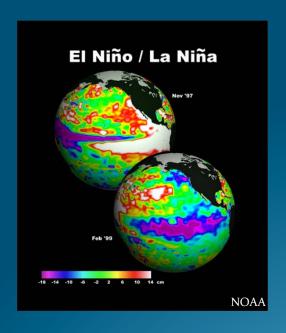
The tropics....

### Oceanic vs Continental Tropical Convective Systems



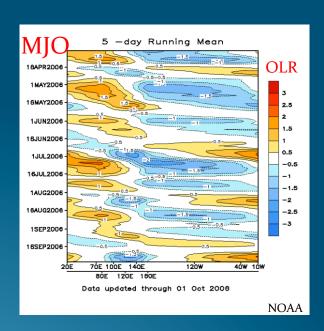


### Control on deep oceanic tropical convection and impact on the climate system





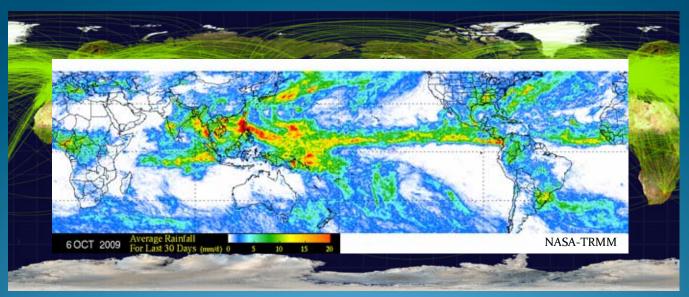




- organization of convection?
- role of convectively coupled waves (e.g. Rossby, Kelvin)?
- feedback between ENSO, MJO convection, tropical cyclones?
- feedback on walker circulation?
- feedbacks between convection and momentum transport, temperature?
- how does convection organize waves, waves organize convection?

# Tropical cloud systems

Microphysical structure of deep tropical convection—intertropical convergence zone and high ice water contents



Wikipedia commons

Clouds, aerosol, climatic effects....

# <u>Clouds and climate</u> aerosol direct and indirect effects/cloud microphysics

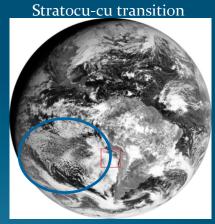
# Has full potential of radar been exploited?

# Oceanic stratocumulus

MODIS/NASA

# Arctic stratus

DOE/ARM



http://www.metoffice.gov.uk/research/news/vocals

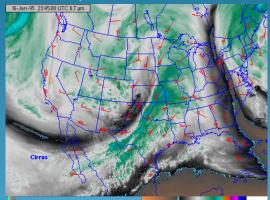
Tradewind cumulus

# Anvil Cirrus



http://ape.ifac.cnr.it/thescamp.htm

## Jetstream Cirrus



**UCAR** 

http://earthobservatory.nasa.gov/blogs/fromthefield/2012/09/21/the-moods-of-sea-and-sky/

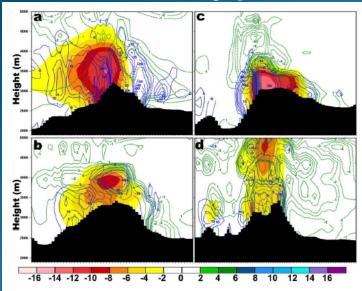


# Orographic precipitation

# Mountains are the source of fresh water for much of the world's populated regions

Changes in aerosol modify microphysical processes significantly, shifting snowfall distribution, and climate warming decreases the fraction of snow by 6%-9% and increases the fraction of rain by an equivalent amount

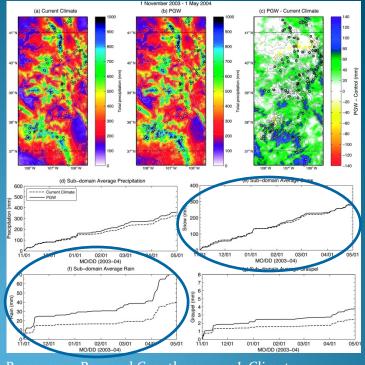
# Aerosol effects on orographic snowfall



Saleeby et al. 2013 JAS (in review)

Change in riming (shaded), depositional growth on water droplets (blue) and depositional growth on ice (green) for CCN= 100 vs 1500 cc.

## Warmer climate effects on orographic snowfall



Rasmussen, Roy, and Coauthors, 2011: J. Climate, 24, 3015-3048



# Orographic precipitation

# Mountains are the source of fresh water for much of the world's populated regions

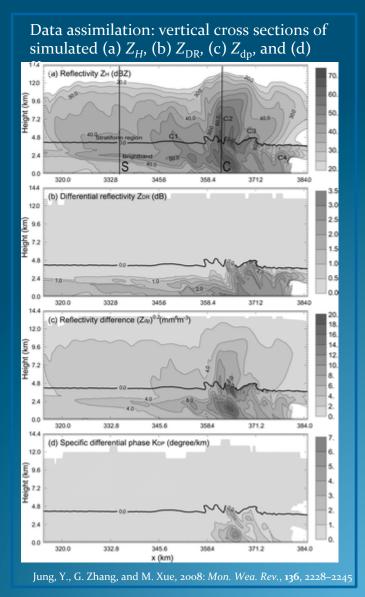
Changes in aerosol modify microphysical processes significantly, shifting snowfall distribution, and climate warming decreases the fraction of snow by 6%-9% and increases the fraction of rain by an equivalent amount

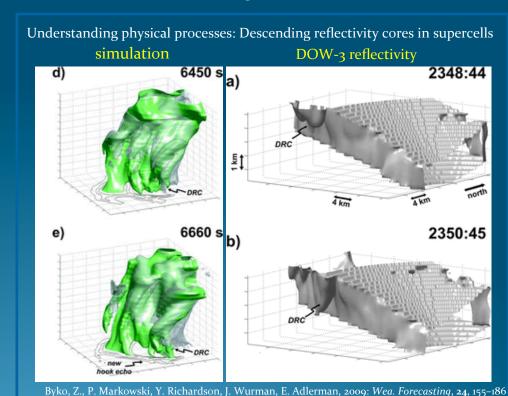
Need for radar research to better understand effects of climate change on orographic precipitation processes and evaluate predictions of orographic precipitation models **Emerging Science Frontiers** 

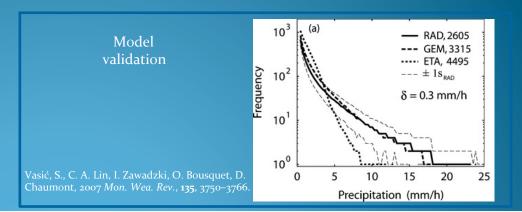
Model Integration

# New frontiers in the coalescence of radar and modeling research

Data assimilation, Model validation, Microphysical/dynamical/thermodynamic studies, parameterization development and testing...

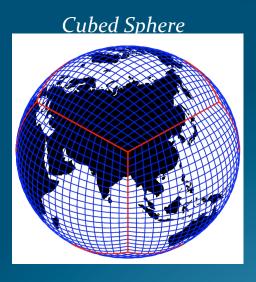




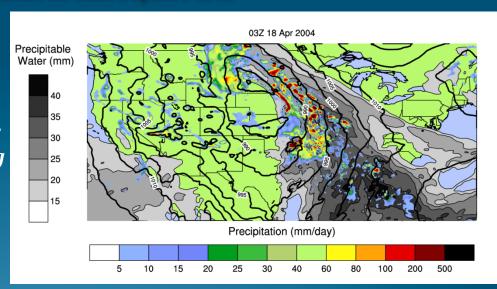


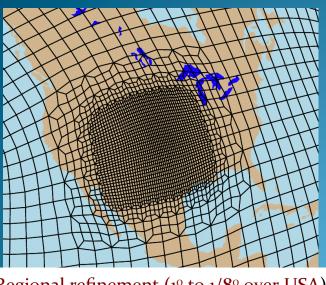
# FRONTIERS OF RADAR RESEARCH IN THE CONTEXT OF NEW MODELING FRAMEWORKS

# High Resolution: New Dynamical Cores CAM5-Spectral Element on Cubed Sphere Grid



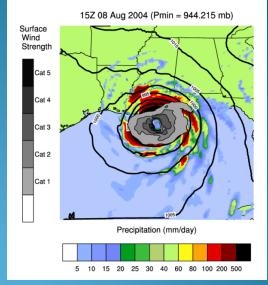
Mid-west Spring time propagating systems





Regional refinement (1° to 1/8° over USA)

**Tropical Cyclones** 



12-km CAM-SE Run

The need for diversity....

# Platform diversity

# SHIPBORNE RADARS





# GROUND-BASED RADARS





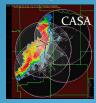
**FULLY-MOBILE** 



FIXED LOCATION



**NETWORKED** 



# AIRBORNE RADARS











# Pointing diversity

# Rapid scanning radars



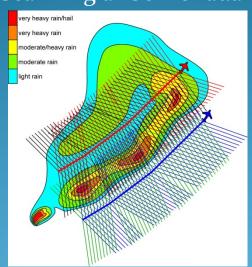
# Profiling radars



# Traditional scanning radars



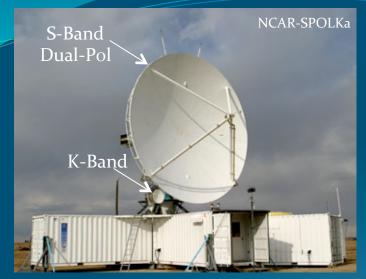
# Scanning airborne radars



# Profiling airborne radars

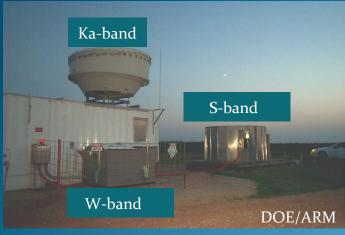


# Wavelength/Polarization diversity





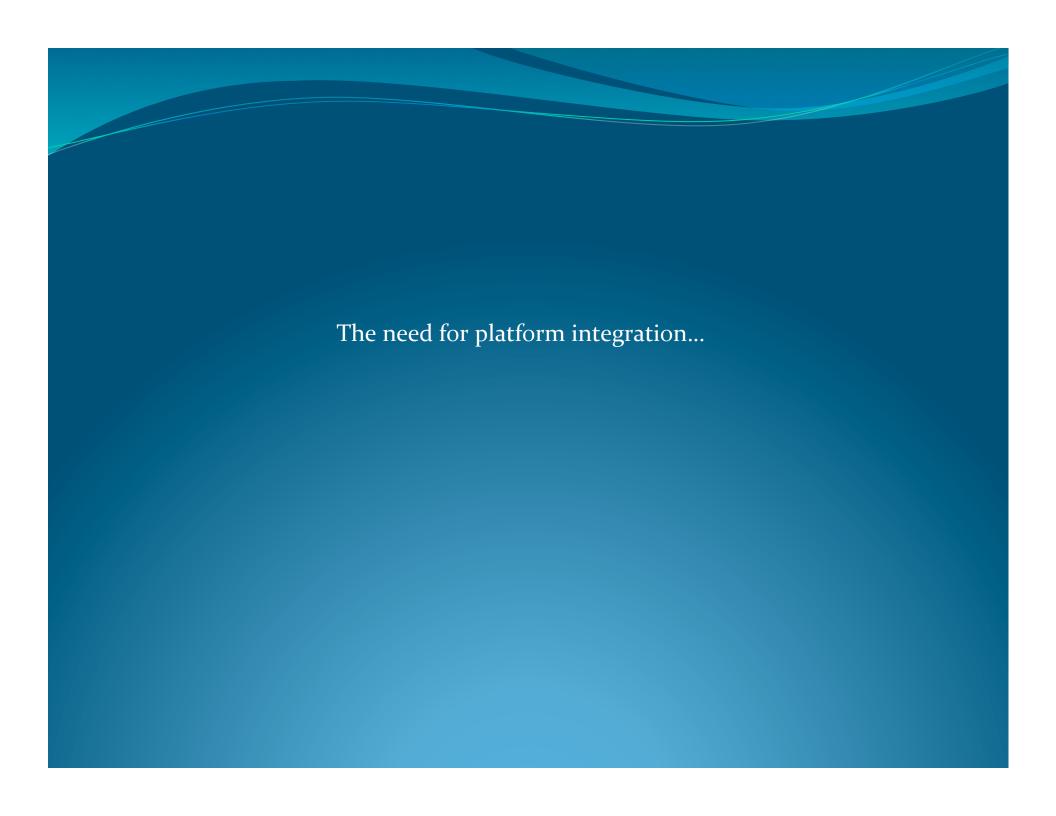






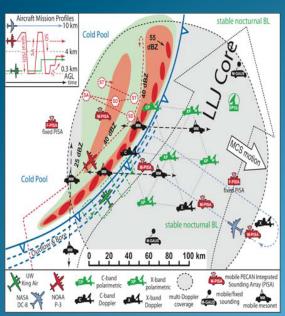


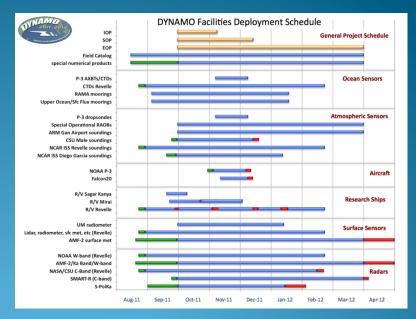




# New frontiers in science will require that radars comprise one component of multi-platform, multi-model investigations of meteorological phenomena

Always been true-but the level of sophistication across platforms and models will increase as the problems to solve become ever more complex





**PECAN** 

**DYNAMO** 

# Central questions of this workshop

During the next 10-20 years...

- 1. What emerging science frontiers will require field research using advanced radar systems? ✓
- 2. What technologies are required to make the necessary measurements with these radar systems?
- 3. How should the radar facilities available to the research community be structured and funded to meet these demands?