NRL Predictability Initiative and SAANGRIA

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SAANGRIA Collaboration: D. Fritts[4], R. Smith[5], M. Taylor[6]

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Outline

NRL Initiative and SAANGRIA

T-REX Experiment and Dataset

COAMPS Predictability Tools

Research Focus for MURI

Mesoscale Predictability

Anthes et al. (1985) (and recently) argued that the predictability of many mesoscale phenomena can exceed that suggested by Lorenz if they are organized by the large-scale (e.g., fronts) or controlled by external forcing (e.g., orography, land use…).


UCAR MAGAZINE

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All of NCAR & UCAR UCAR Magazine

FIRST PERSON

PRESIDENT'S CORNER

Turning the tables on chaos: Is the atmosphere more predictable than we assume?

6 May 2011 • In the fall 2010 issue of *UCAR Magazine*, I discussed the excellent forecast of last year's Hurricane Earl, the societal benefits of such forecasts, and some of the reasons why these forecasts have steadily improved. Here I discuss atmospheric predictability in general and present some remarkable examples of recent successful experimental predictions of some high-impact mesoscale phenomena—the kind of forecasts that may become commonplace ten years from now.

Estimating the predictability of the atmosphere has intrigued philosophers, mathematicians, and scientists for many years. Gottfried Leibniz (1646-1716) imagined seeing the future: "Everything proceeds mathematically . . . if someone could have a sufficient insight into the inner parts of things, and in addition had remembrance and intelligence enough to consider all the circumstances and take them into account, he would be a prophet and see the future in the present as in a mirror." The Marquis de Laplace (1749-1827) dreamed of an intelligent being (later dubbed Laplace's Demon) who knew the positions and velocities of every single atom and used Newton's equations of motion to predict the future of the entire universe.

The search for limits

Nearly two hundred years after Laplace's speculation on deterministic predictability, Edward Lorenz (1917-2008), a meteorologist from MIT (and a frequent summer visitor to NCAR) discovered that perfect deterministic forecasts of weather were impossible. As a young meteorologist, Lorenz had thought that weather would be ultimately as predictable as eclipses, but he later discovered that the growth of small errors in numerical models limited atmospheric predictability to a few weeks. In so doing Lorenz discovered chaos theory, which some have placed alongside relativity and quantum mechanics as one of the three great scientific revolutions of the 20th century.

A good sense of Lorenz's achievements can be gleaned from two papers he wrote in 1963: the descriptive "The predictability of hydrodynamic flow," published in *Transactions of the New York Academy of Sciences* and the classic theoretical paper "Deterministic nonperiodic flow" in *Journal of the Atmospheric Sciences*.

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Questions

- Are mesoscale circulations forced by the synoptic-scale or lower boundary (e.g.,terrain) endowed with enhanced predictability? If so, to what degree?
- What are the characteristics of mesoscale predictability in such situations?
- How do gravity waves influence the predictability?

Approach

- Use adjoints and ensembles to examine mesoscale predictability.
- Focus on initial condition sensitivity, perturbations growth, and scale interactions for a variety of mesoscale flows.
- Make use of field program datasets to test predictability hypotheses.

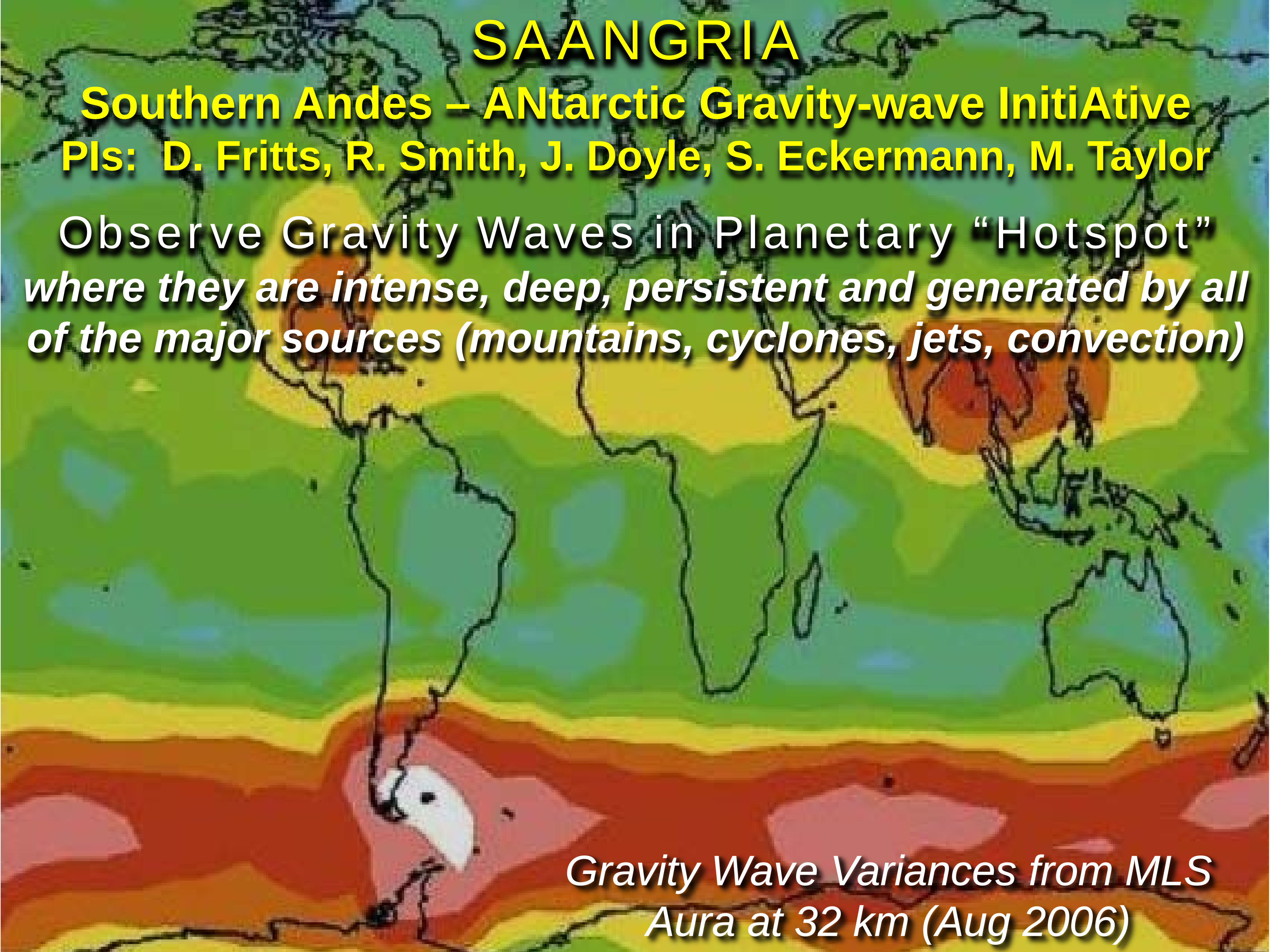
SAANGRIA

Southern Andes – ANtarctic Gravity-wave InitiAtive

PIs: D. Fritts, R. Smith, J. Doyle, S. Eckermann, M. Taylor

Observe Gravity Waves in Planetary "Hotspot"

where they are intense, deep, persistent and generated by all of the major sources (mountains, cyclones, jets, convection)

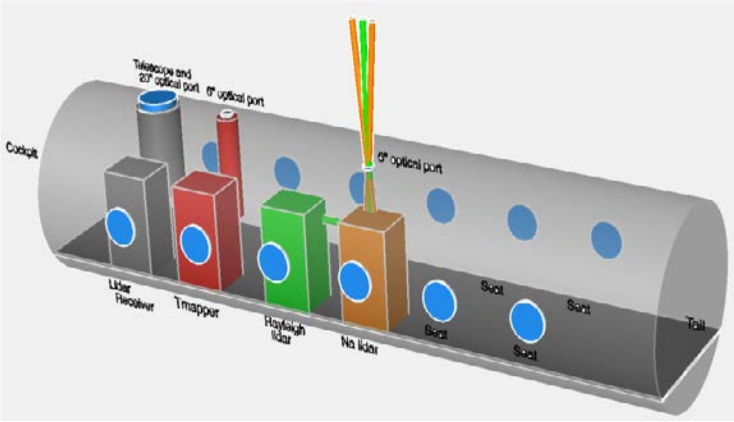


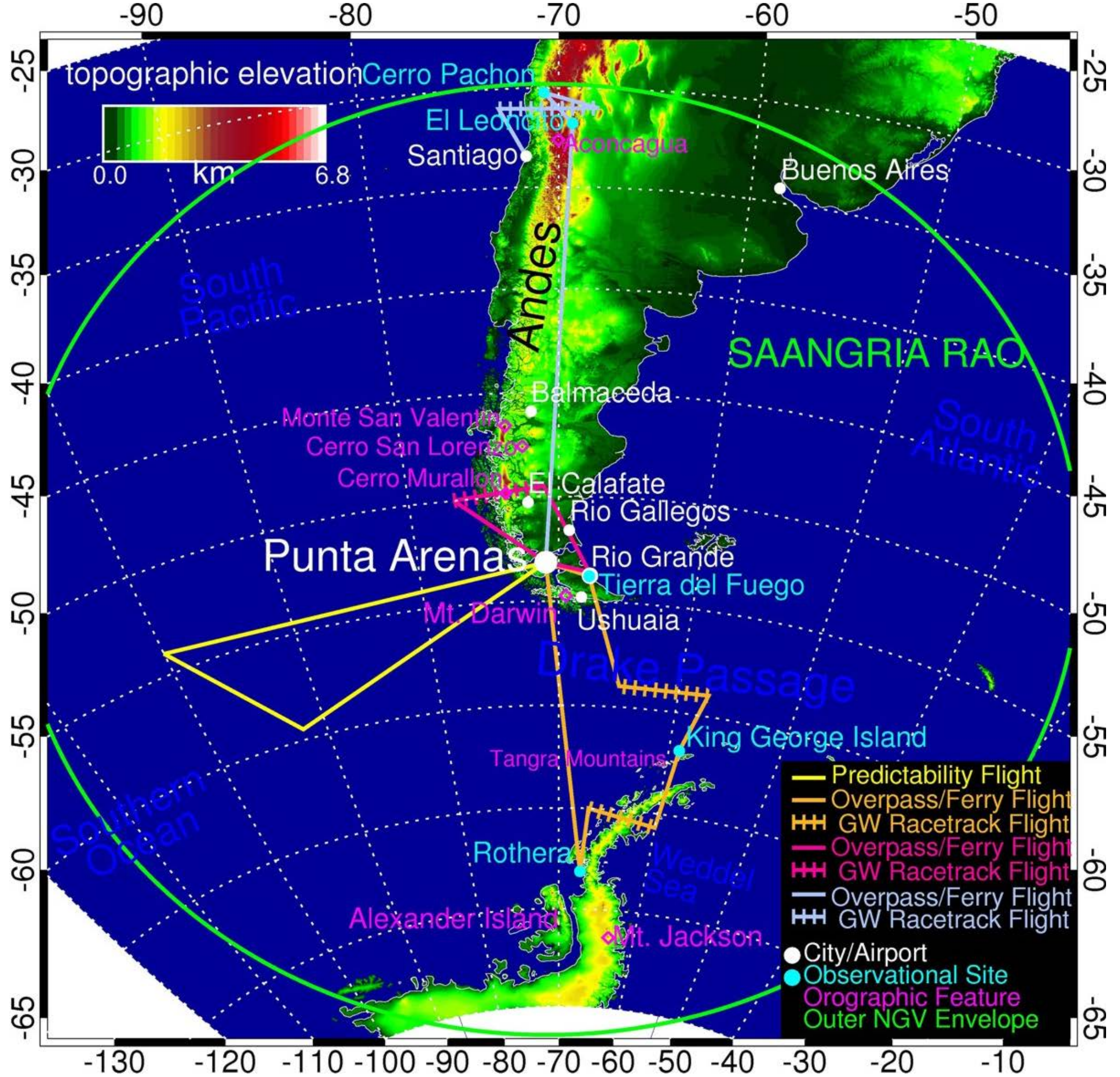
Gravity Wave Variances from MLS Aura at 32 km (Aug 2006)

SAANGRIA Experimental Design

10-week field program in austral winter ~June to September 2013

NSF/NCAR Gulfstream V (NGV)

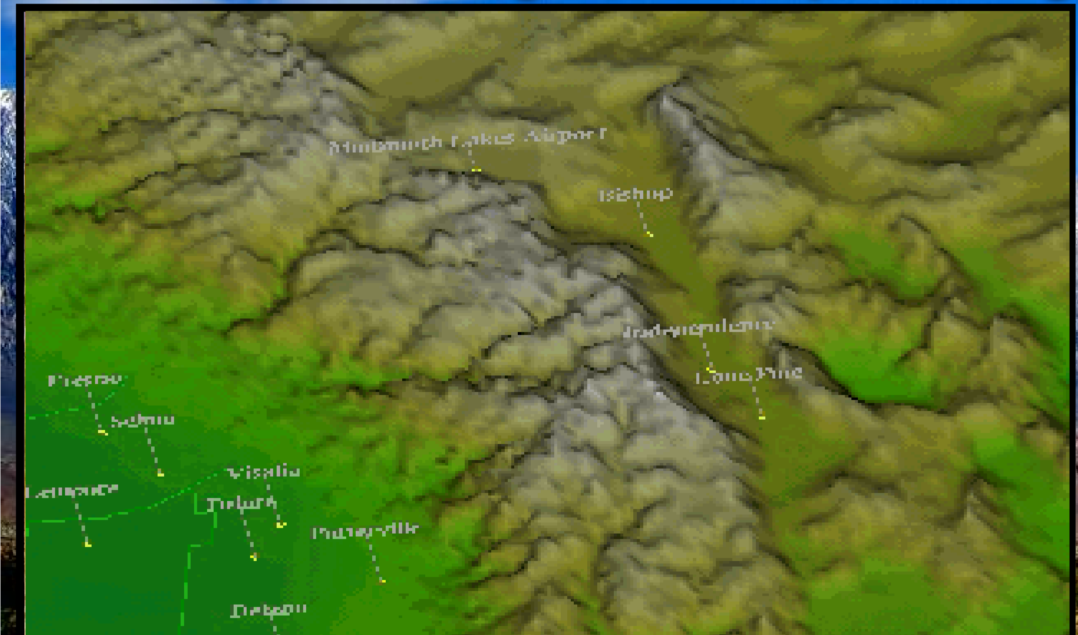


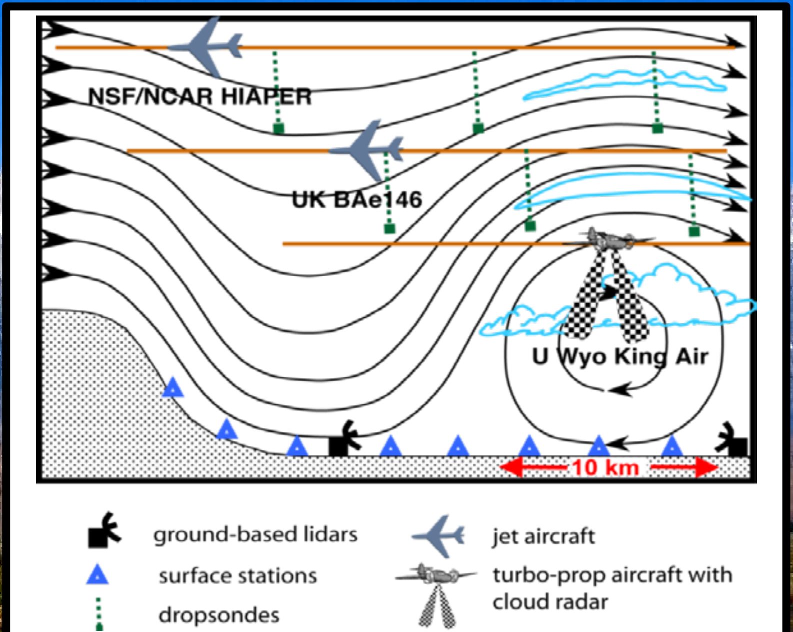


May Include Additional Aircraft (DLR Falcon, UK BAe146, European HALO)

Terrain-Induced Rotor Experiment

- **Objective: Explore rotor, mountain wave dynamics & interaction with BL**
- **Included both mountain rotor and quiescent flow objectives**
- **Sierra Nevada and Owens Valley (March-April 2004 & 2006 with 29 IOPs)**
- **International effort [*NCAR, DRI, NRL, DLR, NOAA, Leeds, Met Office, Universities (Yale, Stanford, Utah, Cal.-Berkeley, Washington, Houston)*], PIs: V. Grubisic (DRI/NCAR/U. Vienna, NSF PI), J. Doyle (NRL)**
- **Observational Assets: 3 aircraft, 3 lidars, radars, profilers, >130 obs**
- **T-REX data catalogue, see http://catalog.eol.ucar.edu/trex/**





Terrain-Induced Rotor Experiment

AMS T-REX Special Collection

(35 papers, BAMS, MWR, JAS, JAMC, JTECH)

Observational, Theory, Modeling, Forecasting, Predictability

THE TERRAIN-INDUCED ROTOR EXPERIMENT

DE WEKKER AND MAYOR

JULY 2009

SPECIAL
Terrain-induced Rotor Experiment (T-REX)
COLLECTION

Observations of Atmospheric Structure and Dynamics in the Owens Valley of California with a Ground-Based, Eye-Safe, Scanning Aerosol Lidar*

STEPHAN F. J. DE WEKKER
University of Virginia, Charlottesville, Virginia

SHANE D. MAYOR+
National Center for Atmospheric Research,# Boulder, Colorado

826 JOURNAL OF APPLIED METEOROLOGY AND CLIMATOLOGY

Wind Profiler Observations of Mountain Waves and Rotors during T-REX

STEPHEN A. COHN
National Center for Atmospheric Research,* Boulder, Colorado

VANDA GRUBIŠIĆ
Department of Meteorology and Geophysics, University of Vienna, Vienna, Austria

WILLIAM O. J. BROWN

Lee-Wave Resonances over Double Bell-Shaped Obstacles

VANDA GRUBIŠIĆ*
Desert Research Institute, Reno, Nevada

IVANA STIPERSKI
Croatian Meteorological and Hydrological Service, Zagreb, Croatia

(Manuscript received 11 July 2008, in final form 2 October 2008)

776 JOURNAL OF APPLIED METEOROLOGY AND CLIMATOLOGY VOLUME 48

Evening Temperature Rises on Valley Floors and Slopes: Their Causes and Their Relationship to the Thermally Driven Wind System

C. DAVID WHITEMAN* AND SEBASTIAN W. HOCH
Department of Meteorology, University of Utah, Salt Lake City, Utah

GREGORY S. POULOS+
National Center for Atmospheric Research,# Boulder, Colorado

(Manuscript received 1 May 2008, in final form 3 October 2008)

Rotors and Sub-Rotors during T-REX

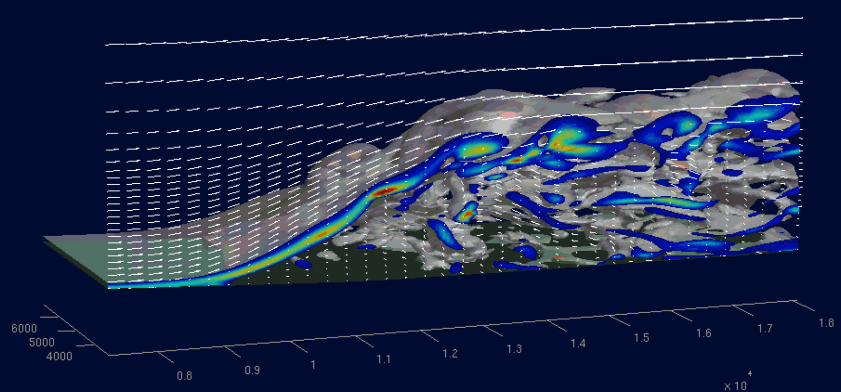
COAMPS Large Eddy Simulation

- Ultra high-resolution simulations of intense subrotor vortices.
- Subrotors intensify via vortex stretching.
- Doppler & aerosol lidars, wind profilers, during T-REX observed similar structures.

COAMPS-LES: Subrotor Vortices

Δx=60 m

2100 UTC 16 April 2007

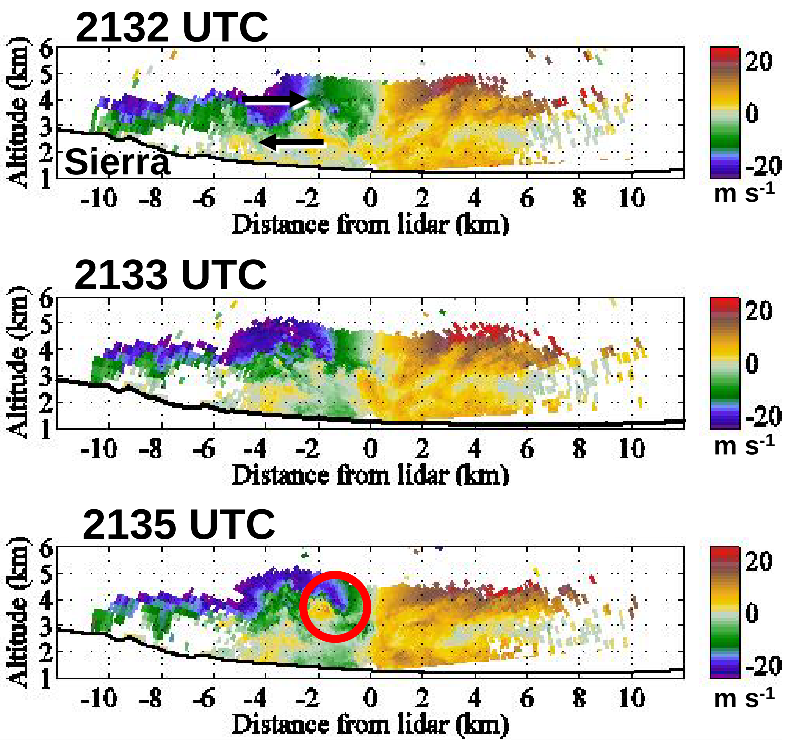


η Vorticity (color)

η = 0.15 s-1 (red)

η = 0.02 s-1 (gray)

DLR Doppler Lidar Velocities



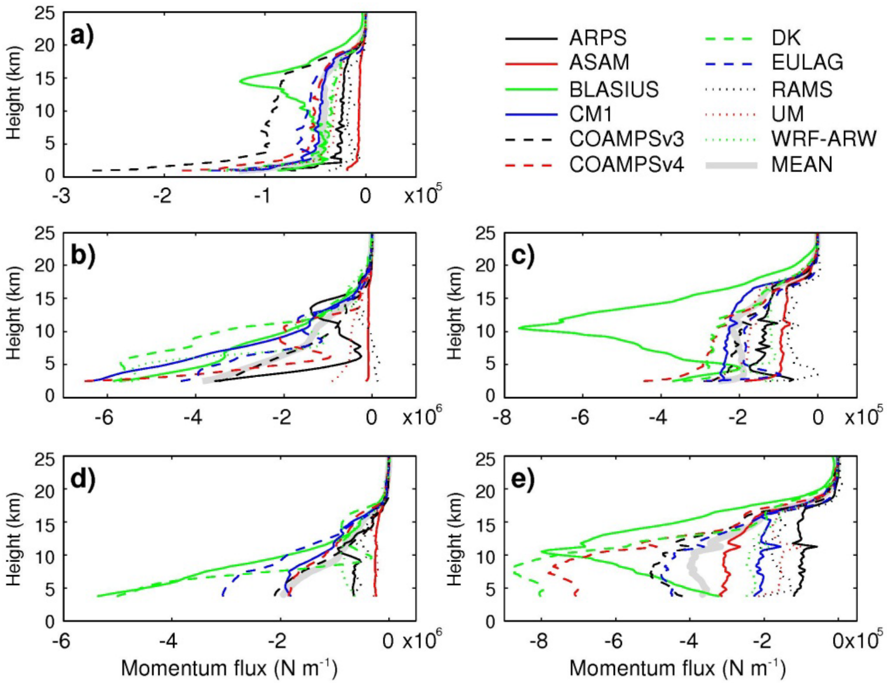
Doyle et al. (2009) JAS

- Very high-resolution models require high-fidelity observations
- Models can guide our search for new fine-scale phenomena.

T-REX Model Intercomparison

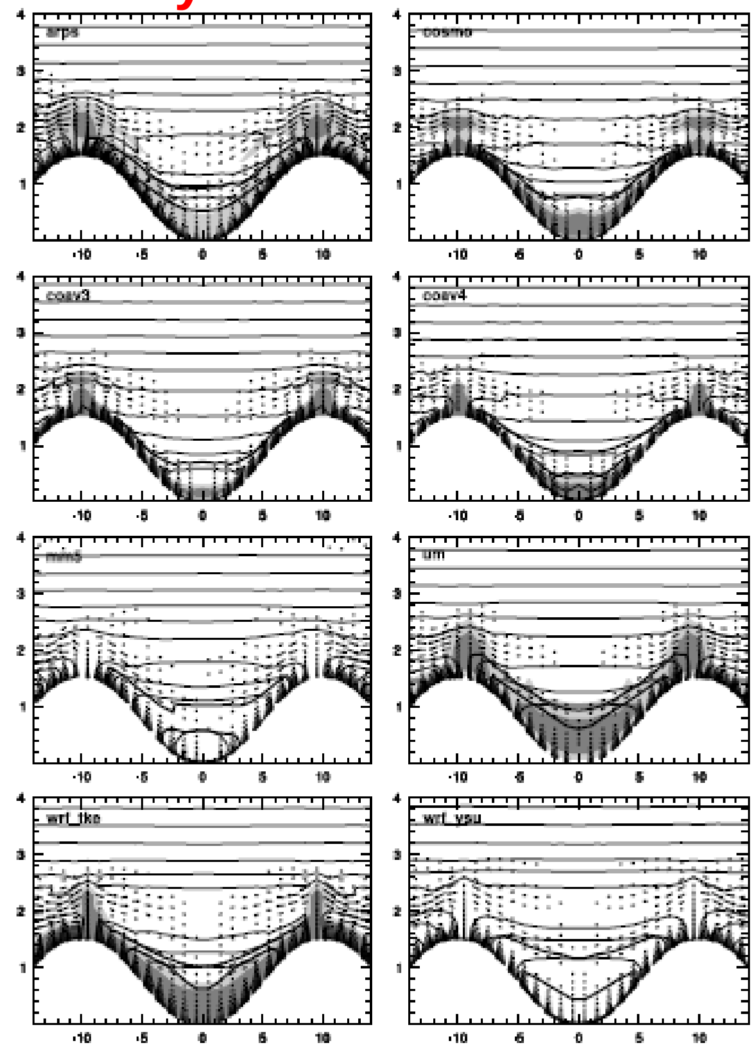
Mountain Wave and Thermally-Forced Flows

Mountain Wave Test Cases



Doyle et al. 2011

Thermally-Forced Flow Test Cases



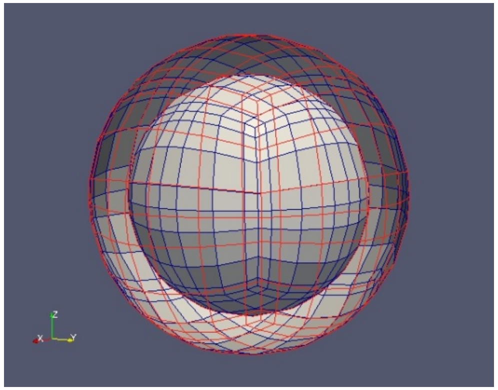
Schmidli et al. 2011

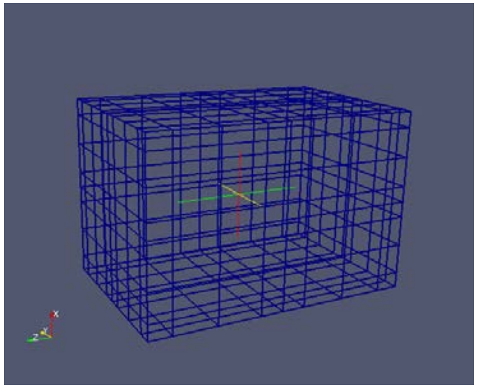
Model Simulations are Surprisingly Diverse for T-REX Test Cases.

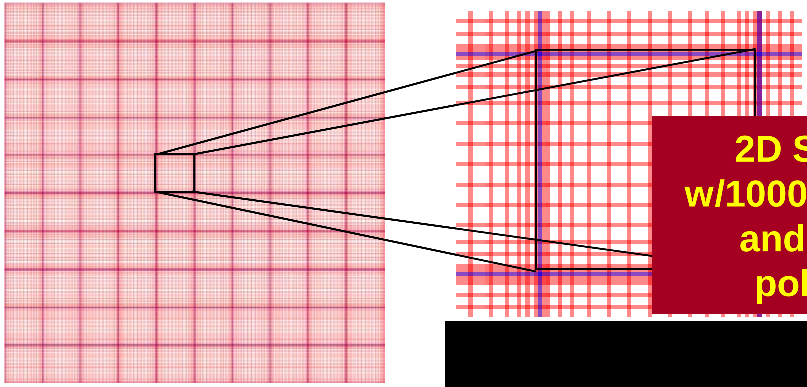
New Dynamical Core

Nonhydrostatic Unified Model for the Atmosphere (NUMA)

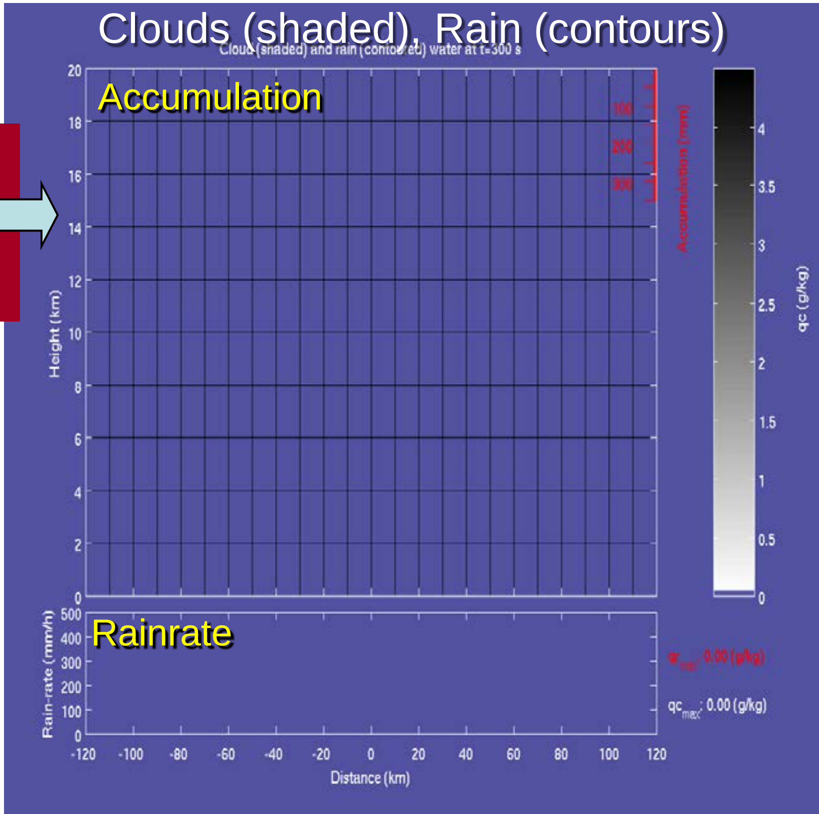
- **Spectral Element Dynamical Core:**
  - High order accuracy
  - Extremely scalable
  - Mesoscale, Global options (w/ MPI)
  - Semi-implicit solver
  - Incorporation of physics underway



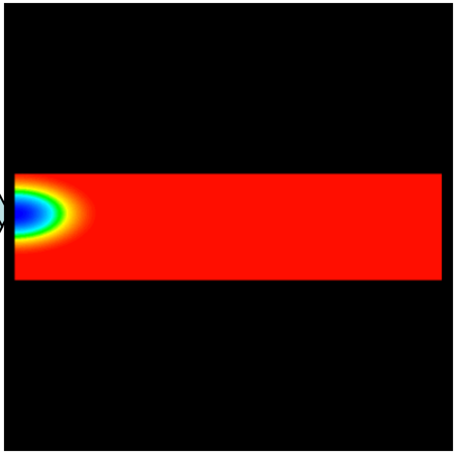




2D Squall Line w/1000 m resolution and 10th order polynomials



Density Current w/50 m resolution and 8th order polynomials

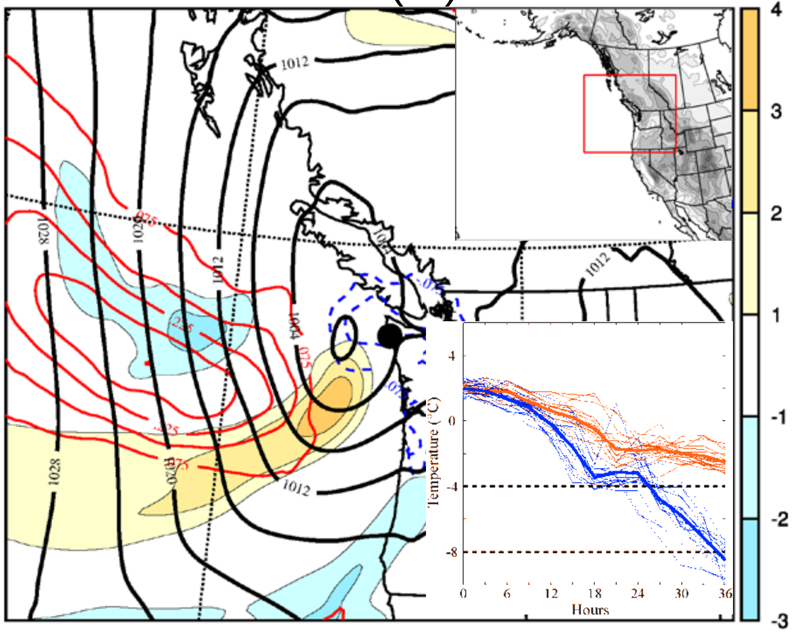


Frank Giraldo (NPS)
Sasa Gabersek (NRL)

COAMPS Predictability Tools

Multi-scale Ensemble and Adjoint Capabilities

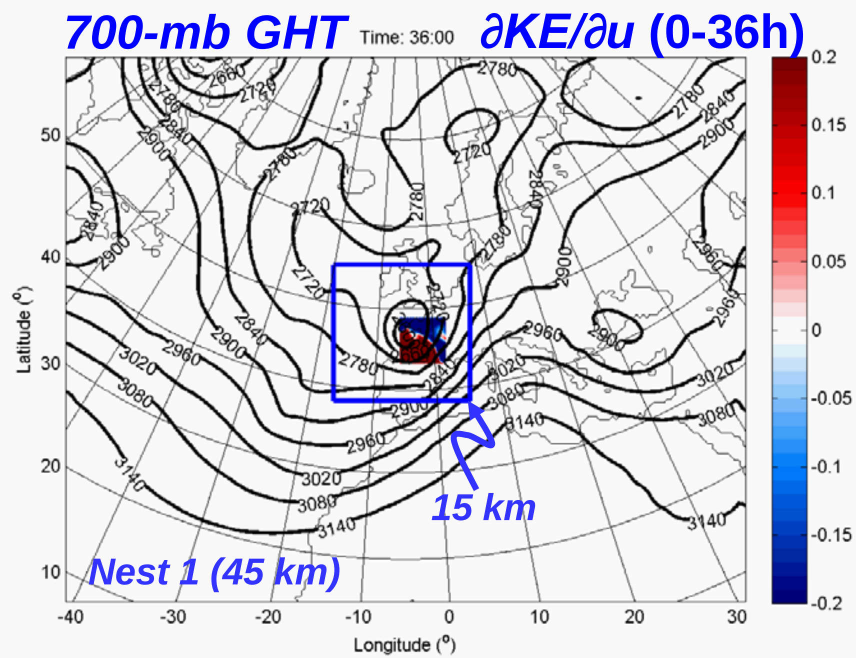
Covariance between SLP and
700 hPa Temp (contours)
700 hPa RH (fill)



- **EnKF-DART capability.**
- **100 member nested ensemble.**
- **Predictability and data impact studies.**

- **Nested adjoint modeling system.**
- **Multi-scale sensitivity and observation impact capability under development.**

36-h Nested Adjoint Run
Severe European Cyclone Xynthia
28 Feb 2010



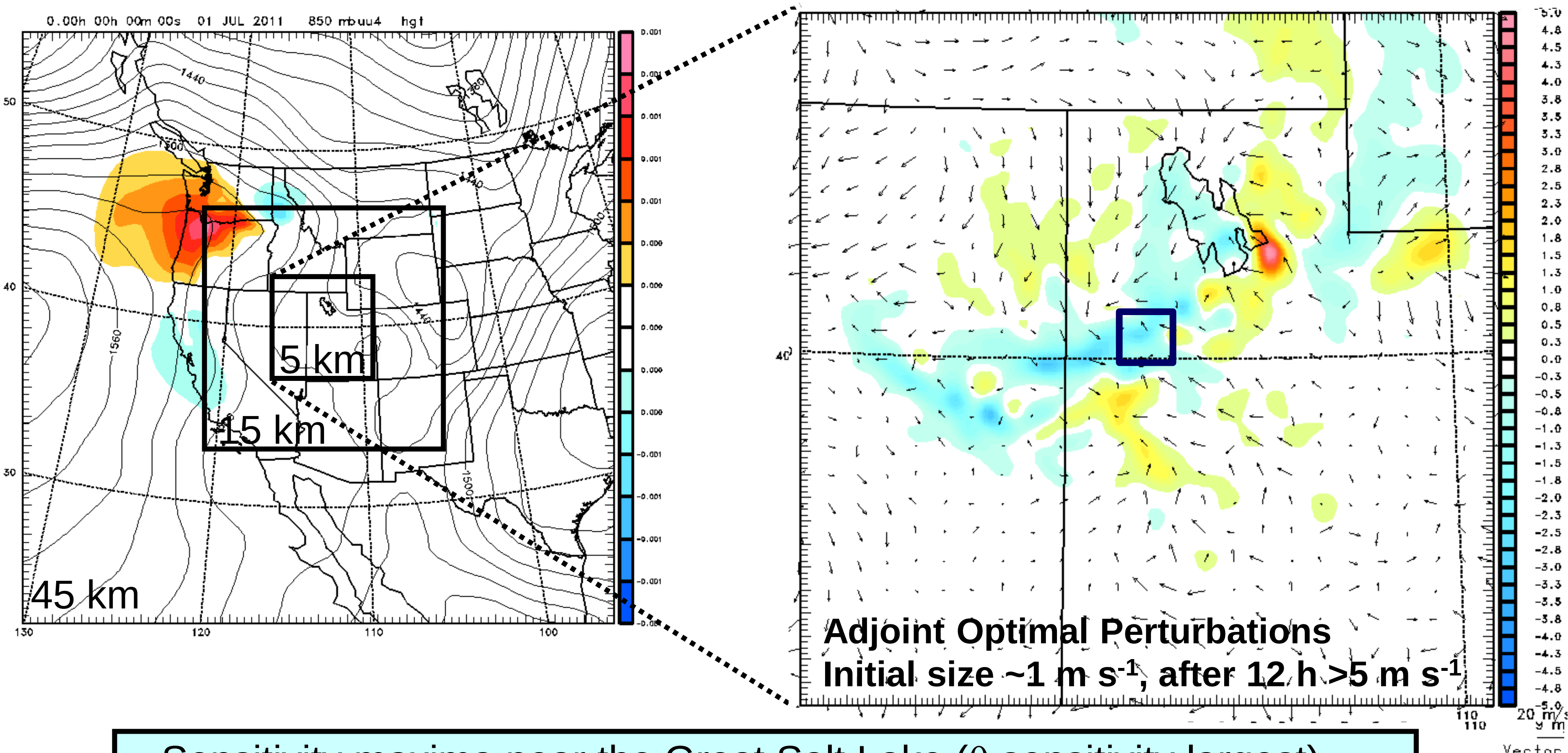
COAMPS Adjoint

Multi-scale Adjoint Summer Example for Dugway

Adjoint 12-h Sensitivity for 00 UTC 1 July 2011

U Sensitivity 850-mb GHT

U Evolved Perturbations (12 h) at 300 m



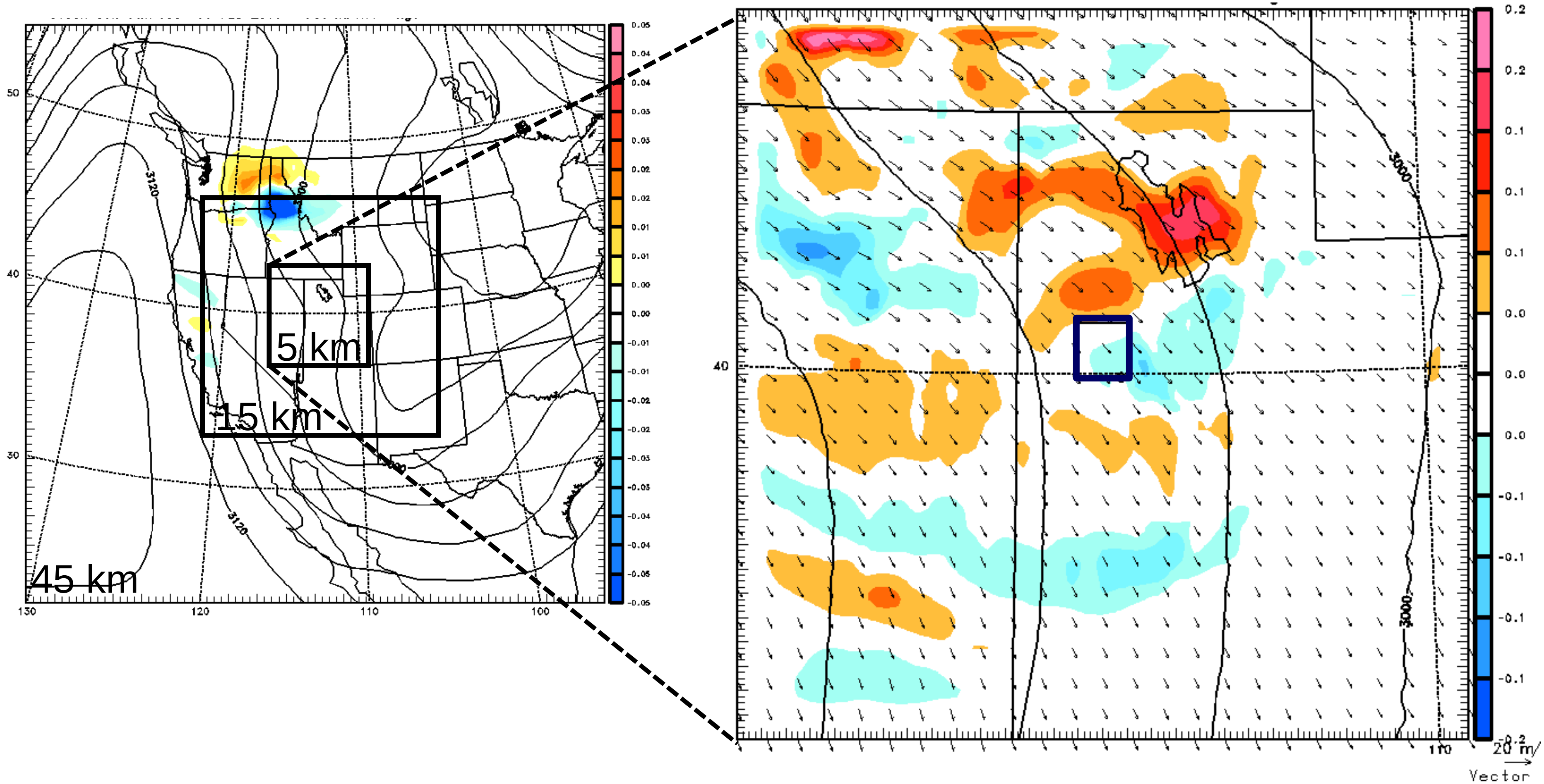
- Sensitivity maxima near the Great Salt Lake (θ sensitivity largest).
- 1 m s^{-1}, 1 K perturbations near lake, grow by 5 times in 12 h.
- Sensitivity is 200 times larger on the fine mesh.
- Winter cass shows greater sensitivity on coarse mesh (stronger flow).

COAMPS Adjoint

Multi-scale Adjoint Winter Example for Dugway

Adjoint 12-h Sensitivity for 00 UTC 1 Feb 2011

θ Sensitivity 700-mb GHT — θ Sensitivity 700-mb GHT, Winds



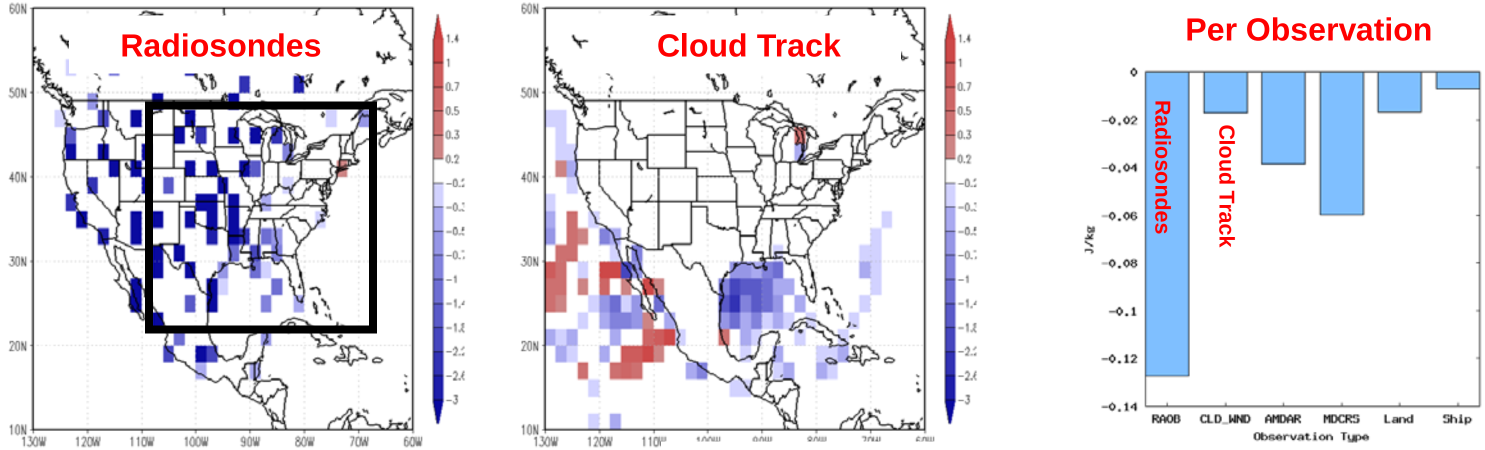
- Sensitivity (12 h) on the coarse mesh comparable to fine mesh.
- Winter case shows greater sensitivity on coarse mesh (stronger flow).

COAMPS Observation Impact System

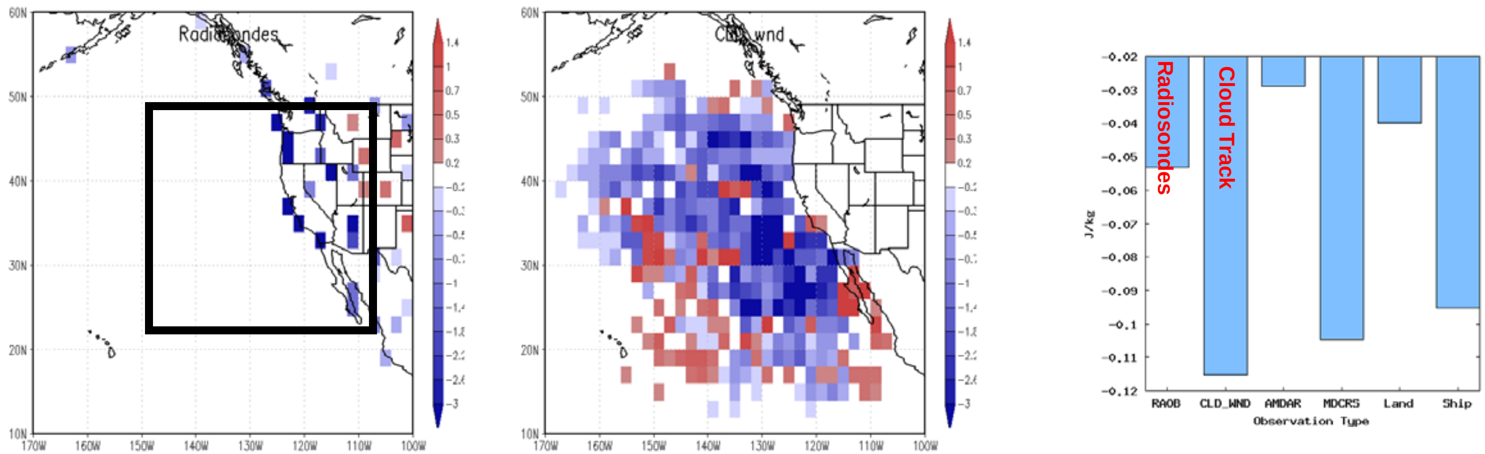
Integration of Data Assimilation and Model Adjoints

COAMPS Impacts 12/24-31 2010

CONUS



EPAC



Observations Impact Derived from Data Assimilation and Model Adjoints

Research Focus

Predictability and Dynamics

- Quantify the predictability limits for terrain-influence mesoscale flows
  - terrain can both enhance and degrade predictability
  - weak vs. strong forcing (winter vs. summer; winds, fog, clouds)
- Quantify the observation impact for the mesoscale and use this information for observing network guidance
  - quantify conventional and nonconventionial observations impact as a function of data density (e.g., data spare regions)
- Gain insight into how gravity waves influence mesoscale predictability
- Compare and understand the strengths and weaknesses of adjoint and ensemble sensitivity approaches
- Continue to build the NRL predictability toolbox for COAMPS
- Collaborate with Matterhorn PIs and incorporate new technology into the Navy's COAMPS