# RESPONSE TO NOAA RESEARCH REVIEW TEAM DATA REQUEST

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**Boulder Colorado**

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**6 February 2004**

## Brief History

The Wave Propagation Laboratory (now ETL), like a number of the original Boulder Laboratories, grew out of the research of the Central Radio Propagation Laboratory in the late 1960s. The laboratory, formed in 1967 under the leadership of Dr. C. Gordon Little, focused on developing remote sensing methods (optical, radio, and acoustical) as a new way to study the geophysical environment. In the 1970s and early 1980s, ETL began focusing on a number of practical problems including applying its acoustical and optical remote sensing methods to the study of regional air quality. The transfer of the boundary layer research group from the Air Force Cambridge Labs to ETL in the mid-1970s accelerated these efforts. In addition, ETL began developing and demonstrating the value of operational networks of radar wind profilers for weather forecasting. In the course of these activities, the Prototype Regional Observing and Forecasting System (PROFS) and the Wind Profiler Demonstration Network were spun off from the laboratory and later formed the nucleus for the Forecast Systems Laboratory in 1988. Most recently, in response to a number of internal and external reviews coincident with the transition in the Laboratory Director in 2001, the laboratory has narrowed its focus to developing and refining remote sensing technology for regional weather and climate applications while maintaining its unique blend of physicists, engineers, and meteorologists necessary to promote science and technology infusion.

## Laboratory Customers

**NOAA Matrix Programs:**

1) **Science and Technology Infusion:** To improve NOAA's ability to observe, describe, understand and forecast the Earth's environment with a particular emphasis on the interaction of the atmosphere with the Earth's surface (Land, Ocean, and Cryosphere) and the development of observationally-based weather-climate testbeds.
2) **Air Quality:** To improve the characterization of meteorological processes affecting air quality, to assess and diagnose model performance (particularly in the planetary boundary layer), and to implement observational and diagnostic testbed activities that lead to improved air quality forecasts.
3) **Climate:** To advance understanding of the aerosol indirect effect and role in climate forcing.
4) **Fisheries Management:** To advance technology for measuring fish stocks and characterizing the physical state of the ocean using remote sensing.

**Other NOAA Customers/Support:**

1) **Office of Global Programs:** To carry out fundamental studies of climate processes with a particular emphasis on atmosphere-ocean interaction and the North American Monsoon.
2) **Climate Observations and Services:** To increase our understanding of the connection between weather and climate on intraseasonal time scales with a focus on tropical-extratropical interactions and downscaling to regional coastal watersheds.
3) **NWS:** To assess and evaluate NWS models on a regional basis so as to test and improve the characterization of surface processes in the model that affect their

temperature forecasting skill. To improve coastal observations for coastal storm prediction.

4) **NWS/Office of Hydrology/Water Resources:** To improve the observations and understanding of hydrometeorological processes that influence NOAA's performance on its flash flood and quantitative precipitation forecasting (QPF) performance metrics. Advances have helped improve NOAA services in demonstration studies and future work will aid in developing and evaluating a distributed hydrologic model required by NOAA.
5) **USWRP:** To improve quantitative precipitation forecasting, particularly in coastal areas, through the implementation of hydrometeorological testbeds.
6) **SEARCH:** To increase our ability to observe and diagnose climate change in the Arctic through long term observations and field campaigns.
7) **NESDIS/NPOESS:** Provide advanced technology and modeling expertise for evaluating and planning new satellite sensors for measurements of global winds and to develop technology and carry out experiments related to specification and performance of a space-based global wind sensing system.
8) **JCSDA:** To develop fast algorithms for microwave radiance assimilation to increase the use of NOAA satellite data**.**

**External Customers/Support:**

1) **State Agencies (Texas & California):** To transfer scientific and technological advances from the NOAA air quality program and to utilize efforts funded at the State level to meet NOAA's needs.
2) **DOE:** To provide meteorological information essential to energy applications and climate studies.
3) **ONR:** To provide improved understanding and quantification or processes at the ocean surface.
4) **USDA:** To develop means of mapping soil moisture for agricultural purposes.
5) **NASA:** To improve the utilization of satellite data for monitoring the Earth's environment.
6) **DOD:** To advance understanding of the planetary boundary layer, particularly under stable conditions; to contribute to observational issues related to national security, drawing from the unique remote sensing expertise in ETL; to improve weather observations required for DOD operations.

## Research Motivation and Summary

ETL's major focus lies in the area of Science and Technology Infusion and is motivated in large part by the requirements laid out in the NWS Science and Technology Infusion (STI) Program Baseline Assessment (PBA) (PBA available: https://www.ppbs.noaa.gov/pbas.html; STI Summary available: http://www.weather.gov/ost/ ). ETL has developed three primary focus areas for its research based on STI planning and documents developed over the last three years:

***1) Using Regional Science and Technology Testbeds to Advance the Transfer of Research to Operations –*** *ETL maintains a broad suite of ground-based and airborne remote sensing instruments that support local and regional studies of atmospheric, oceanic, and surface processes necessary to advance NOAA's capability to observe, understand, and predict weather, climate and air quality. This instrument suite is now supporting a number of testbed deployments to accelerate the transfer of science and technology into operations.*

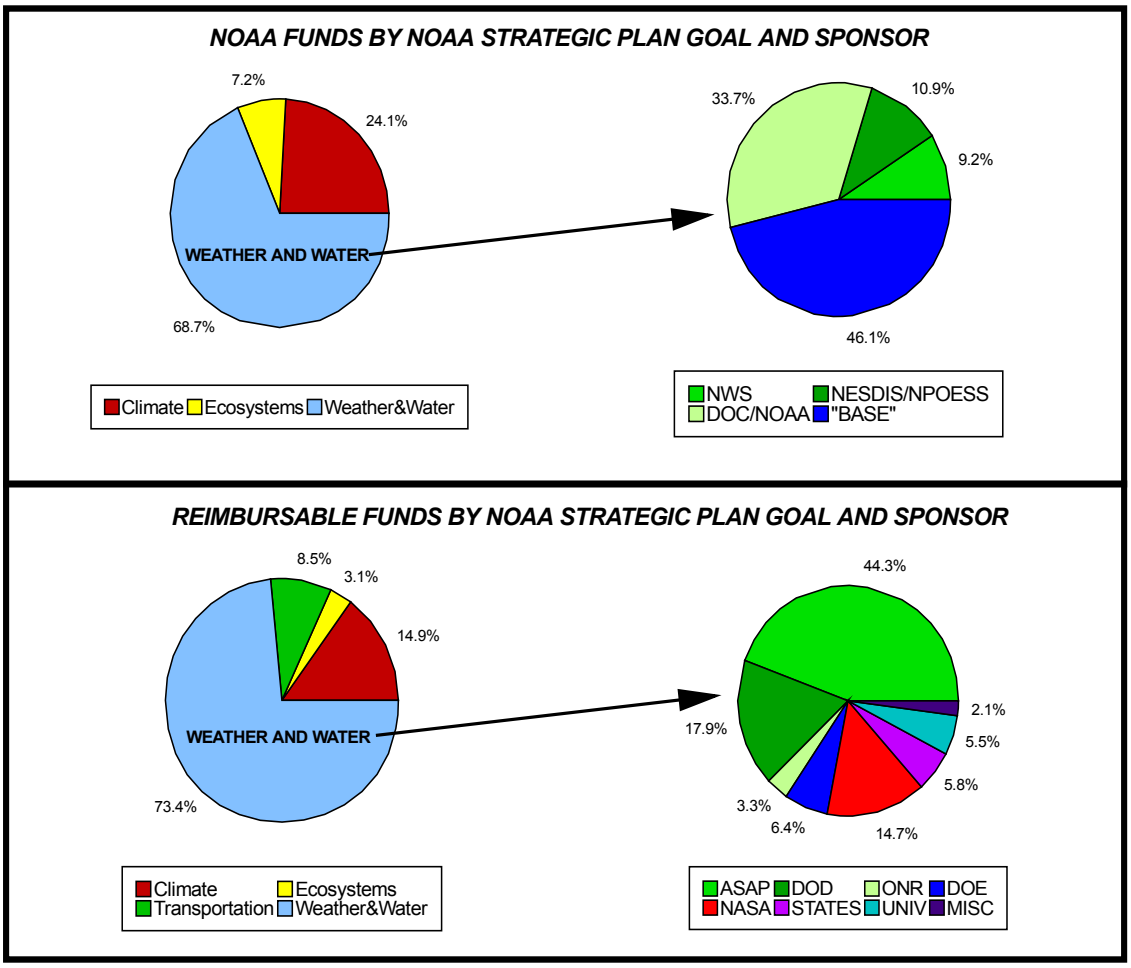
***2) Understanding and Describing Processes at the Interface of the Atmosphere with Land, Ocean and the Cryosphere –*** *ETL's long history of boundary layer research grew from the early insights provided by acoustic, optical and radio remote sensing instruments, gaining a major impetus in the mid-1970s with the transfer of the AFCRL boundary layer turbulence team, famous for the Kansas field studies in the 1960s, to the lab and the construction of the Boulder Atmospheric Observatory 300-m meteorological tower. Since that time, our program has expanded with major contributions to climate-relevant parameterizations for air-sea interaction, using NOAA's unique seagoing capabilities, to pioneering new observing capabilities in the polar regions, and to embracing the NWS Science and Technology Infusion Plan that calls for a focus on the boundary layer in "situationally-sensitive" regions, a focus that is particularly important for improving coastal and air quality forecasting.*

***3) Understanding and Describing the Atmosphere: Weather, Climate, and the Processes That Connect Them –*** *The ability to observe and diagnose the state of the atmosphere for weather and climate applications has been greatly enhanced by ETL's development of remote sensors. For example, ETL's leadership in developing cloud and radiometric remote sensing gave rise to many of the commercial remote sensors now deployed at the DOE's Clouds and Radiation Testbed site. ETL's demonstration of the value of wind profiler networks in Colorado motivated the creation of the Profiler Demonstration Network in the U.S. mid-west. ETL's experience in deploying remote sensing systems in remote areas of the oceans and polar regions will underpin decisions for the next generation global observing system. In addition, ETL's observational and diagnostic capability will support new efforts in understanding processes and impacts that lie between weather and climate time scales.*

Within the Laboratory, we balance our NOAA funding from "Base" and Program enhancements with support from other line offices and other federal agencies. Each project is classified on the basis of its relevance to NOAA Strategic Goals, NOAA Matrix and Program areas, and ETL Focus Areas, as described in the Appendix. Our research is primarily long-term in nature with short-term and medium-term transition efforts. For example, our boundary layer

expertise cuts across numerous science and technology infusion topics but can be applied to immediate operational needs as described in our selected accomplishments listed in the next section.

The following figure provides an overview of our NOAA and external funding for Fiscal Year 2003 (NOAA funds support about 60% of the ETL annual cost):




## Major Accomplishments

### *Using Regional Science and Technology Testbeds to Advance the Transfer of Research to Operations*

- **Temperature Forecasting: Observations and Model Assessment**
  - ETL evaluated model meteorological fields with observed fields in a multi-laboratory/NWS field study in 2002, revealing problems with cloud-radiation feedbacks in the models and confirming the physical justification for model improvements planned by NCEP. NCEP evaluated its planned modifications to the Eta model during the spring of 2003 and found an improvement of nearly 1.5 $^{o}$F in the forecast maximum daily temperatures for New England. The changes were transferred to the operational

Eta model in July 2003 and are now being evaluated by ETL using a special summer 2003 field deployment in preparation for a more extensive regional study in New England in the summer of 2004.

- **Air Quality Forecasting: Observations and Model Assessment**
  - ETL deployed for the first time an ozone and aerosol lidar on the NOAA ship *Ron Brown* during the 2002 New England Air Quality Study to characterize the processes affecting the vertical structure of ozone and aerosol over the cold ocean. The transport and mixing of pollutants over the ocean is a major issue for evaluation in forecast models for the Northeast. The summer 2004 field program will focus on this issue with enhanced instrumentation on the *Ron Brown*.
  - For the NOAA Health of the Atmosphere field research programs and Congressionally supported studies conducted for the California Air Resources Board, ETL deployed networks of integrated boundary-layer observing systems to observe and characterize important parameters for air quality including the depth and strength of convective vertical mixing, aerosols and ozone, diurnal wind patterns and surface radiation. Based on feedback from NWS forecasters and forecast users, ETL is developing two new web-based tools. The first is a real-time display of convective boundary-layer (CBL) depth derived from the Doppler spectral moments collected by the wind profilers. The second is a wind profiler trajectory tool that will allow users to plot forward or backward trajectories on a map based on the horizontal winds collected by the wind profiler network. These tools will be available for forecasters and research scientists during the 2004 New England Air Quality Study.

- **Coastal Hydrometeorology: Technology Development, Observations and Application**
  - Creation of a NOAA Hydrometeorological Testbed (HMT) involving several OAR labs and branches of NWS.
  - Developed and demonstrated a new method using boundary layer wind profilers to monitor the snow-level in winter storms on the US West Coast and in New England. Evaluated the use of these data by NWS/WFOs through web-based feedback.
  - ETL deployed a prototype gap-filling X-band dual-polarization radar to explore its potential for filling gaps in current NEXRAD coverage with much improved measurements of rainfall rates, particularly for watersheds in mountainous regions.
  - ETL has developed a fast radiometric Jacobian algorithm that incorporates both absorption and scattering, thus facilitating the direct assimilation of passive microwave satellite data under all weather conditions. The routine is being tested and packaged for use within the NCEP operational assimilation system in collaboration with the JCSDA.
  - ETL trained NWS river forecasters and meteorologists at COMET training courses in 2002 & 2003.

***Users and Benefits:*** The primary user is the National Weather Service in providing better forecasts of temperature with current models and in preparing for forecasts of air quality with models now being developed for operational use. In the case of the coastal hydrometeorology testbed program, this grew out of a series of shorter-term winter experiments (CALJET, PACJET) that directly involved water managers, emergency managers, flood control agencies,

fishermen associations, harbor masters and others. The current plan is to bring researchers, forecasters and forecast users together to develop, test, evaluate and recommend permanent, cost-effective solutions to limitations in current observing systems, model parameterizations, forecasting techniques, and understanding of key physical processes. These goals are manifested in the creation of a Hydrometeorological Testbed (HMT) in 2003 based on input from across NOAA's NWS, OAR and NESDIS line offices, as well as input from forecast users.

## *Understanding and Describing Processes at the Interface of the Atmosphere with Land, Ocean and the Cryosphere*

- **Quantifying air-sea transfers of heat, momentum, and $CO_2$**
  - ETL worked with its Woods Hole partners to foster the development of a $CO_2$ version of the NOAA/COARE bulk flux algorithm which has now become the standard for estimating $CO_2$ fluxes over the ocean. This work has been characterized as an important breakthrough by NOAA's Carbon Cycle Program.
  - ETL collaborated with scientists at the Woods Hole and Australia's CSIRO to develop and update (most recently in 2003) an algorithm to compute air-sea fluxes from bulk meteorological variables. COARE is the most accurate algorithm available and its wide use for weather, climate, and research applications has established it as the global standard (it has been referenced in more than 400 scientific publications).
  - ETL cooperated with scientists from the University of Washington to obtain the first ever ship-based remote sensing observations of marine stratocumulus clouds as part of NOAA's CLIVAR research program. The measurements included mm-wavelength Doppler cloud radar, Doppler lidar, wind profilers, air-sea turbulent fluxes, radiative fluxes, and balloon soundings.

- **Advancing the remote sensing on the Earth's land, ocean, and ice/snow surfaces**
  - ETL developed the first practical airborne techniques for regional mapping of soil moisture, and had demonstrated the first such application of dual C- and X-band radiometry for this purpose. This system was demonstrated in airborne campaigns over Iowa, Alabama, Georgia, and Oklahoma in 2002 and 2003, and will be used during NAME in 2004.
  - NOAA/ETL is the first institution prior to the launch of WindSat that had succeeded in demonstrating two-dimensional mapping of the near-surface ocean wind field using passive polarimetric radiometry. The ETL effort in this area has been in direct support of the NPOESS Integrated Program Office on the development of the passive polarimetric wind vector concept, scheduled to be used on board the first NPOESS satellite in 2009.
  - ETL developed the first airborne Lidar for fishery surveys. ETL has demonstrated good agreement between LIDAR data and echo-sounder data in tests on epiphelagic fishes in the Gulf of Mexico off Florida and in the Gulf of Alaska, juveniles of a number of species in the Atlantic off the Iberian Peninsula, mackerel off Norway, and zooplankton in Prince William Sound, Alaska. An imaging capability has been added that allows individual salmon to be identified and counted.
  - ETL developed a new high-resolution, multi-sensor, blended satellite sea surface

temperature (SST) data set that combines the through-cloud measurement capability of microwave sensors with the high accuracy and resolution of infrared sensors.

***Users and Benefits:*** The major beneficiary of ETL's air-sea interaction program has been the global climate modeling community with secondary use of the parameterizations now occurring in NCEP weather models. ETL's program in airborne remote sensing and multi-sensor products benefit NOAA's other line offices including NESDIS and NMFS.

## *Understanding and Describing the Atmosphere: Weather, Climate, and the Processes That Connect Them*

- **Improving Arctic Climate and Weather Forecasting**
  - Developed state-of-the-art radars, radiometers and flux systems that are Arctic hardened and capable of operational monitoring as well as portable field operations together with creating retrieval techniques to blend data streams from multiple sensors to determine atmospheric properties that can not be determined from one system alone. ETL is leading the effort to establish the first SEARCH Arctic Observatory site.
  - Generated multi-year, archived data sets of cloud macro- and microphysical properties, boundary and surface-layer structure and turbulent exchanges, and surface energy budgets for coastal Arctic and Arctic Ocean locations.
  - Improved a hierarchy of forecasting (e.g. ECMWF), climate (e.g. CCCMa, CCSM) and regional (e.g. ARCSYM, MM5) models with new observation-based parameterizations as well as providing unique data sets for model validation.

- **Demonstration of new technology to measure critical atmospheric variables over mesoscale domains**
  - ETL demonstrated the first high resolution remote measurements of boundary layer moisture transport and fluxes during the International H2O Project by combining airborne measurements from Doppler and water vapor lidars. The observations enabled characterization of transport of moisture by the southerly low level jet at much smaller scales than are available from dropsonde or radiosonde observations.

- **Observing and Modeling Clouds, Aerosols and Radiation**
  - Using a unique combination of remote sensors and models, ETL has engaged in a study of the aerosol indirect effect. Observations are provided by surface-based remote sensors developed at ETL and enable simultaneous profiling of aerosol entering clouds (measured by lidar) and cloud drop response (derived from radar and microwave radiometer). Our models include detailed representation of aerosol and cloud microphysics and the effect of aerosols on cloud drop number and size, and cloud reflectance.
  - ETL fabricated and is testing a prototype Ground-based Remote Icing Detection System (GRIDS) to remotely identify hazardous in-cloud aircraft icing conditions and issue warnings to pilots and air traffic controllers. This system, being developed for the NWS and FAA, is based on a number of microwave and radar technologies pioneered at ETL.
  - To solve the problem of assimilating passive microwave data into forecast models over heavy clouds, ETL has developed fast discrete ordinate radiative transfer model routines

that provide the Jacobian between the observed brightness temperature and all NCEP prognostic parameters. This program uses ETL's unique theoretical expertise in radiative transfer and numerical weather modeling.

- **Exploring Issues at the Interface Between Weather and Climate**
  - ETL Played key role in developing the international THORPEX effort that has now been transferred with staff to OAR HQ.
  - Developed the Weather Climate Connection effort with CDC, with initial results documenting watershed-scale sensitivity to large-scale flow patterns influenced by tropical forcing, and exploring the climatology of atmospheric rivers and their role in linking the tropics and land-falling west coast storms.

***Users and Benefits:*** Observations and diagnostic activities in the polar regions are critical to observing and diagnosing climate change, validating new polar satellite data products, and supporting NOAA's SEARCH efforts. Other efforts support the CCSP as well as the activities of the USWRP, NASA/NOAA Joint Center for Satellite Data Assimilation (JCSDA), and NOAA/NWS/NCEP/EMC, and NWS aviation forecast validation.

## Legal Mandates

The legal mandates for ETL's efforts can be derived from those outlined in the Science and Technology Infusion Program Baseline Assessment (pages 11-16 and Appendix A therein). Available: https://www.ppbs.noaa.gov/pbas.html

## APPENDIX: ETL Project Classification

**NOAA GOAL:**

- E: Ecosystems
- C: Climate
- W: Weather and Water
- T: Transportation

**NOAA Matrix/Program Specific** (Note: these are the four major programs in which ETL's NOAA "base" $ are distributed and to which reimbursable funding is mapped)

- F_: MG1: Fisheries Management
  - F1: Fish Lidar
  - F2: Salinity
- C_: MG2:
  - C1: Climate-Aerosols
  - C2: The Weather Climate Connection
- S_: MG3: Science and Technology Infusion (STI)
  - S1: Water Resources/Hydrology
  - S2: Severe Weather (tornadoes, thunderstorms, flashfloods, winter storms, hurricanes)
  - S3: Coastal/Maritime Issues (proposed Coastal, Estuaries, and Ocean Program)
  - S4: Aviation (ceiling, visibility, turbulence, icing)
  - S5: Climate
  - S6: General (Explain in Comments)
- Q0: MG3: Air Quality (in the process of transfer from STI)

**ETL Thrusts:**

*T_: Using Regional Science and Technology Testbeds to Advance the Transfer of Research to Operations*

- N: New Technology
- R: Refining Technology
- D: Demonstrating/Assessing Technology
- S: Applying technology to answering scientific problems
- A: All the above

*P_: Understanding and Describing Processes at the Interface of the Atmosphere with Land, Ocean and the Cryosphere (PBL)*

- L: Land
- O: Ocean
- C: Cryosphere
- A: All the above

*U_: Understanding and Describing the Atmosphere: Weather, Climate, and the Processes That Connect Them*

- C: Clouds, Aerosols, and Radiation
- W: Water issues
- P: Polar weather and Climate
- I: Intraseasonal-to-Interannual: The Weather-Climate Connection
- G: General (Explain in Comments)

*I_: Research Infrastructure*

- F: Facilities (e.g. BAO, Erie, etc)
- G: General Science and Support