Excerpted in January 2007 from the GHATTEX Revised Proposal dated 1 March 2001

This document presents a scientific and technical approach to using the Global Hawk UAV in a scientific demonstration project. The document is the original NASA proposal modified by the removal of cost and proprietary information and certain appendices. (D. Fahey and A. Tuck, January 2007)

A Revised Proposal to:

Office of Earth Science (OES)
National Aeronautics and Space Administration
Washington, DC 20024

In response to:

A Letter of Invitation
January 8, 2001

NRA-00-OES-02
UAV-Based Science Demonstration Program

TITLE:	The Global Hawk Tropical Tropopause Experiment (GHATTEX): Exploring the tropical tropopause region of the Pacific Ocean with the Global Hawk UAV platform
AWARDEE:	Aeronomy Laboratory National Oceanic and Atmospheric Administration 325 Broadway R/AL6 Boulder, CO 80305-3328
PRINCIPAL INVESTIGATOR:	Dr. Adrian F. Tuck 303/497-5485 303/497-5373 (fax) tuck@al.noaa.gov
CO-PRINCIPAL INVESTIGATOR:	Dr. David W. Fahey 303/497-5277 303/497-5373 (fax) fahey@al.noaa.gov
DATE OF REQUEST:	1 March 2001

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The Global Hawk Tropical Tropopause Experiment (GHATTEX)

National Oceanic and Atmospheric Administration Aeronomy Laboratory
Boulder, Colorado

Fact Sheet

Mission Purposes

- Demonstrate the utility of the large payload capacity, high cruise altitude, and long endurance of the Global Hawk for atmospheric research.
- Observe the distribution of radiatively and chemically important species on large spatial scales in the tropical Pacific region.
- Study radiative transfer, atmospheric chemistry, and dynamics in the tropical upper troposphere and lower stratosphere and their relation to global climate processes.

Instrument Payload

- Methane (CH_4), ozone (O_3), water vapor (H_2O), carbon dioxide (CO_2), aircraft-level temperature and pressure, temperature profiles, background particles (4 nm to 1 μm), Ice Particles (0.5 to 60 μm)

Global Hawk UAV

- Demonstrated capability to take a 680-kg (1500-lb) payload to 20 km (65000 ft) for 32 hours, cruising at 350 knots; to date (17 January 2001) the aircraft has flown 759 hours in 65 flights.

Project Team

- ***Management***

Dr. A. F. Tuck	Project PI	NOAA AL
Dr. D. W. Fahey	Project Co-PI	NOAA AL
Dr. G. Hübler	Project Coordinator	NOAA AL
lLt. A. Wehner	Global Hawk Programs	U.S. Air Force ASC/RAV
Mr. G. Loegering	Global Hawk Manufacturer	Northrop Grumman Ryan Aero. Ctr.
Dr. S. Buhr	Education/Public Outreach Coordinator	CIRES, U of Colorado

- ***Instrument Team***

Dr. B. W. Gandrud	PMI, Inc.	Ice particles (MASP)
Dr. R. S. Gao	NOAA AL	Carbon dioxide
Mr. K. K. Kelly	NOAA AL	Water vapor
Dr. M. J. Mahoney	NASA JPL	Temperature profiles (MTP)
Dr. E. C. Richard	NOAA AL	Ozone and methane
Mr. T. L. Thompson	NOAA AL	Temperature and pressure
Dr. J. C. Wilson	U of Denver	Small particles (FCAS III/NMASS)

- ***Theory Team***

Dr. M. J. Alexander	NWRA/CORA	gravity wave studies
Prof. R. A. Plumb	MIT	modeling studies of chemistry and transport
Dr. K. H. Rosenlof	NOAA AL	meteorological support
Prof. M. H. Hitchman	U of Wisconsin	atmospheric transport modeling
Prof. R. E. Newell	MIT	modeling of atmospheric processes
Prof. D. W. Waugh	Johns Hopkins U	modeling of atmospheric processes

- ***Technical Support***

Ms. S. J. Hovde	NOAA AL	data archive and Internet support
Mr. R. H. Winkler	NOAA AL	instrument control and data acquisition

Flight Plans

- Two types of flights in both a summer and winter deployment, with flight levels between 45,000 and 65,000 ft.:
  - *Meridional TransEquatorial flight* **25 hours, Edwards AFB (34°N) to 35°S and return.**
  - *Triangular TransPacific flight* **32 hours, Edwards AFB (34°N) to (7°N, 135°W) to (7°N, 155°E) and return.**

Data Analysis Topics

- Radiative balance near the tropical tropopause.
- Mixing and recirculation between and within the upper troposphere and lower stratosphere.
- Particle production near the tropical tropopause.
- Tropical dynamics, i.e., gravity wave studies, large-scale stratospheric reverse Walker circulation.
- Scale invariance and its relation to mixing and transport processes.

GHATTEX Executive Summary

(Excerpted January 2007)

GHATTEX will make well-calibrated, high-accuracy observations of water vapor, ice particles, aerosols, ozone, methane, carbon dioxide, temperature profiles, and meteorological variables near the tropical tropopause on the scale of the Pacific Basin. The measurements will be made with long-heritage instruments onboard the proven, long-endurance high-altitude Global Hawk UAV. Global Hawk is provided by the U. S. Air Force and built and operated by Northrop Grumman Ryan Aeronautical Center. The aircraft has demonstrated capability to take a 680 kg (1500 lb) payload to 20 km (65000 ft) for 32 hours cruising at 350 knots; to date (17 January 2001) it has flown 759 hours in 65 flights.

GHATTEX mission flights in the upper troposphere and lower stratosphere will originate from California and will occur in pairs in winter and summer deployments. The Triangular TransPacific flight will reach the longitude of Australia with a large transect along the equator. The Meridional TransEquatorial flight will cross the equator deep into the Southern Hemisphere. The scientific return from the flight data interpretation will include (i) quantifying terms in the radiative balance of the upper troposphere and lower stratosphere to better define the response of the atmospheric circulation to climate change; (ii) examining particle production near the tropopause to quantify terms in the stratospheric aerosol budget; (iii) providing evidence on scales from those of local gravity waves to that of the Walker Cell to better define the role of gravity waves in climate, and (iv) examining the scale invariance of trace species and meteorological variables in the upper troposphere and lower stratosphere over an unprecedented wide range of horizontal scales, as a way of improving the numerical modeling of the atmosphere.

GHATTEX is made possible by the cooperation and support of the U. S. Air Force (USAF) Reconnaissance Systems Program Office (ASC/RAV) at Wright Patterson Air Force Base and Northrop Grumman Ryan Aeronautical Center (NG-RAC), the provider and the manufacturer of the Global Hawk UAV, respectively. The GHATTEX Project Team is led by Dr. A. F. Tuck, Principal Investigator, from the NOAA Aeronomy Laboratory. He is supported at NOAA by Dr. D. W. Fahey, Co-Principal Investigator. The Team includes highly experienced individuals from NOAA; Particle Metrics, Inc.; the Jet Propulsion Laboratory/Caltech; the University of Denver; the University of Colorado's Cooperative Institute for Research in Environmental Science; Colorado Research Associates Inc.; the Massachusetts Institute of Technology; the University of Wisconsin at Madison; and The Johns Hopkins University. The aeronautical engineering and flight operations will be managed cooperatively by ASC/RAV and NG-RAC. The total cost and financial risk to NASA in the GHATTEX project is lowered by the substantial *in-kind* contribution from the NOAA Aeronomy Laboratory totaling approximately 27% of that requested from NASA.

1.0 Introduction

The design and construction of uninhabited aerial vehicles (UAVs) has grown substantially in the last decade. The use of UAVs for environmental research and monitoring is often cited in describing the value of these new platforms. The performance goals of UAVs, as with all aircraft, include a varied combination of payload, range, and cruise altitudes. The upper troposphere and lower stratosphere (UT/LS) have long been considered central regions for the maintenance of the radiative balance and hence of climate, particularly in the Pacific [*Doherty and Newell*, 1984; *Holton et al.*, 1995]. This location is also believed to be the site where much of the air which enters the stratosphere crosses the tropopause, although this view has been questioned recently; the subject is controversial [*Jackson et al*., 1998; *Dessler*, 1998]. This near-tropopause region in the tropics between 150 hPa and 50 hPa is a central one for radiative transfer, for dynamics and for chemistry. Although data are limited in this region, notable data sets are available from profiles of the NASA ER-2 aircraft and about 15 flights of the NASA WB-57F aircraft into the Central American tropical area during the recent WAM (1998) and ACCENT (1999) projects. These flights have provided enough observations of water, cirrus, aerosol, ozone, methane and carbon dioxide content to hint at the variety and complexity of the processes likely to be involved, and to raise important questions. They do not however provide a clear picture of how the composition of the region is maintained.

GHATTEX will use the Global Hawk UAV to fly an established, proven payload of chemical, microphysical and meteorological instruments near the tropical tropopause on the scale of the Pacific Basin. The tropical Pacific is the "firebox of the circulation," a key element of the world weather system. Our goal is to provide the atmospheric sciences community with new observations of gases and particles made over a wide range of longitudes and latitudes in the upper troposphere and lower stratosphere (UT/LS) and use these data to address key processes related to atmospheric circulation and climate. Using the proven capabilities of the Global Hawk and its chosen payload is the most economical way to acquire these data from a highly remote region.

GHATTEX observations include methane, ozone, water vapor, carbon dioxide, ice particles, small particles, and temperature profiles. The interpretation of the flight data will include (i) quantifying terms in the radiative balance of the UT/LS to better define the response of the atmospheric circulation to climate change; (ii) examining particle production near the tropical tropopause to quantify terms in the budget of stratospheric aerosols; (iii) providing evidence of gravity waves and large-scale circulation in the UT/LS to better define their role in climate; and (iv) examining the scale invariance of trace species and meteorological variables in the UT/LS as way of evaluating and improving the numerical modeling of the atmosphere.

The Global Hawk is the only UAV with performance specifications suitable to meet GHATTEX objectives. The Global Hawk is the recipient of the 2001 Collier Award from the National Aeronautics Association. It has demonstrated capability to take a 680-kg (1500-lb) payload to 20 km (65,000 ft) for 32 hours cruising at 350 knots and, as such, represents a major step forward in the platform resources available for atmospheric research. This new aircraft has been proven in 65 test and mission flights totaling over 759 airborne hours. The capacities of Global Hawk provide GHATTEX with substantial margins for the payload mass, volume, and power. Most of the proposed payload instruments have a long heritage, evident in the data acquired by them in NASA ER-2 and WB-57F high-altitude missions since 1987.

The use of the aircraft – payload combination of the Global Hawk UAV offers an exciting future for atmospheric science research. The highly experienced project managers, science team, and engineering and flight operations personnel assembled for GHATTEX are confidently poised to take the first steps into this future.

1.1 Revised Proposal Structure

This Revised Proposal follows NASA guidelines for describing Science and Technical Approach, Management and Cost, and Education and Outreach Plan. The GHATTEX Implementation Plan was submitted to NASA's Office of Earth Science on January 31, 2001. This Proposal incorporates substantial material from the **Implementation Plan**, which is attached here as **Appendix I**. The Proposal references further material from the Plan throughout the text using the prefix '**IP-**' for references to figures, tables, and sections.

The scientific aspects of GHATTEX are described in Sections II and III of the original proposal submitted to NASA's Office of Earth Science on 27 April and 8 May 2000. Subsections from the original proposal include Scientific Background (II.A), Science Objectives (II.B), Scientific Capability of the Payload (II.C), Relation to Office of Earth Science Themes (II.D), Scientific Flight Planning (III.F), and Data Analysis and Interpretation (III.H). These sections are reproduced here in their entirety in **Sections 2.0 - 2.4**. No changes have been made to the text except to modify figure numbers and section headings to be consistent with the format used here in the Revised Proposal.

2.0 Scientific Perspective

2.1 Scientific Background

A variety of science studies will be possible with data collected during GHATTEX. Here we give a sampling of the scientific issues of interest.

- **Radiative balance.** In the tropics, the troposphere above the Earth's surface becomes optically thin to infrared radiation above about 14 km. This means that the radiative behavior of the scale height above this altitude will be sensitive to those entities (trace gases, aerosols and temperature) which affect the absorption, emission and scattering of radiation in the layer. The system is highly interactive, particularly through the coupling of water abundance and its phase changes with the vertical temperature structure and deep convection. The quantities needed for an accurate simulation of the system will be measured with high accuracy over long spatial scales for the first time during GHATTEX.

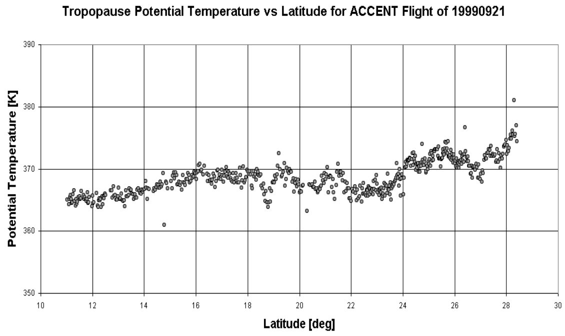

Figure 2.1-1. The potential temperature of the tropopause, obtained by MTP during a WB-57F flight from San Jose, Costa Rica to Houston, TX on September 21, 1999, during ACCENT.

Convection, radiation and large-scale upwelling all likely play a role in maintaining the height of the tropical tropopause [*Thuburn and Craig,* 1997]. In spite of numerous studies over several decades (see *Highwood and Hoskins* [1998] and references therein), a thorough understanding of the basic physics associated with the tropopause is lacking [*Thuburn and Craig,* 2000]. Detailed high-resolution measurements of radiatively active trace species (H_2O, O_3) and the vertical temperature structure coupled with cloud and aerosol information surrounding the tropopause are needed to further untangle questions regarding tropopause maintenance. The proposed GHATTEX flights would allow acquisition of such data over a large spatial scale that could be incorporated into models examining tropopause physics.

Some of the WAM and ACCENT flights by the WB-57F between 30˚N and 5˚N near 95˚W have provided informative observations at, above and below the tropical tropopause in spring and fall. One of these was the potential temperature of the tropical tropopause, θ_{TROP}, made by the MTP and plotted as a function of latitude in **Figure 2.1-1**. Not only does the value of θ_{TROP} for the flight of September 21, 1999, show a slope from low values at inner tropical latitudes to values 10 to 20 K higher at latitudes near the subtropical jet stream (25º N to 30º N), but the inner tropical values are greater than the largest equivalent potential temperatures found at the tropical surface. Therefore, some processes not accounted for by equilibrium thermodynamics must be operating. We will investigate the hypothesis of horizontal transport of higher potential temperature air from the mid-latitude lower stratosphere to the lower-latitude troposphere. Ozone and methane measurements should provide indicators of this transport. With the long-range capability of the Global Hawk, we will be able establish them twice over the entire width of the tropics in a single flight. Such transport would tend to destabilize the tropical UT/LS to vertical air parcel motion, and so allow underlying convection to rise to higher altitudes than in the surrounding air. In addition, we will use total water and cirrus observations from the Global Hawk in conjunction with satellite cloud top data and Lagrangian analysis to examine whether this constitutes a "pumping" mechanism by which near surface air is transported to and through the tropical tropopause.

- **Mixing and recirculation.** There is evidence from the NASA ER-2 transit flights between Hawaii and Fiji in 1994 that species with higher abundances in the Northern Hemisphere troposphere (relative to the Southern Hemisphere) were also more abundant in the Northern hemisphere lower stratosphere. This implies that either the deep convection in the ITCZ does not mix Northern Hemisphere and Southern Hemisphere air in equal proportions, or that upward transport across the tropopause north and/or south of the ITCZ is a significant mechanism [*Tuck et al.*, 1997]. The Global Hawk meridional transect flights will be able to test these ideas.

In addition to questions regarding the mixing of Northern Hemisphere and Southern Hemisphere air within tropical convection, questions also remain as to the degree of mixing between tropical and mid latitude air contained in the lower stratosphere. Several studies [*Volk et al*., 1996; *Minschwaner et al.*, 1996; *Herman et al.*, 1998 and others] have attempted to quantify the amount of lower stratospheric isentropic mixing. Data from GHATTEX would contribute to such estimates by providing first time measurements spanning the width of the ITCZ.

Recirculation of air between the upper troposphere and lower stratosphere has been suggested on the basis of localized vertical profiles by the NASA ER-2. This has implications both for particle production and the exact chemical composition of air which enters the stratosphere. It is known that maintaining mass continuity in the lower stratosphere requires that the majority of mass flux upwards in the inner tropics through 100 hPa (16.5 km) actually flows poleward, with only a small amount continuing upward through the 60-hPa (19.5-km) surface. Calculations [*Rosenlof et al.*, 1997] put the ratio of fluxes at 6, implying that 1/7 of the air ascending through the 100 hPa surface between 10˚N and 10˚S in the annual zonal mean continues upwards through 60 hPa. The remaining 6/7 must move poleward and eventually downward. Some portion of that which moves downward likely mixes back into the upper tropical troposphere. Evidence from tropical ER-2 tracer data exists for recently tropospheric air in the lower stratosphere, and recently stratospheric air in the upper troposphere. Mid-latitude air from the lower stratosphere is found in both the outer and inner tropics above, at and below the tropical tropopause. It follows that some air recirculates between the upper troposphere and lower stratosphere. Our proposed flights will allow an examination of the implications of recirculation for such concepts as the age of the air [*Hall and Plumb,* 1994], the tropical pipe [*Plumb,* 1996], and the tropical tape recorder [*Mote et al.*, 1996], with many observations over a very wide range of scales.

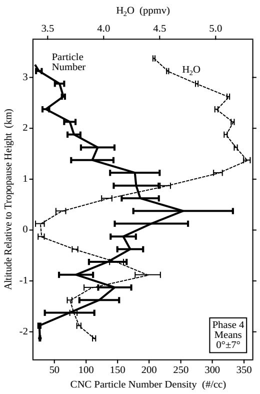

Figure 2.1-2. The abundances of condensation nuclei and total water plotted as a function of altitude from the tropical tropopause within 7º latitude of the equator by the ER-2 during ASHOE-MAESA. October 1994 average.

- **"Mirror-image" Walker circulation.** Based upon vertical wind measurements from profiling radars it has been suggested that a "mirror image" of the long-established tropospheric Walker circulation exists in the lower stratosphere over the tropical Pacific, spanning the entire basin [*Gage et al.*, 1991]. The case is reinforced by maps of outgoing longwave radiation (OLR) from satellites; namely, OLR is a minimum above the high, cold, thick cirrus shields situated above the convective upwelling in the western tropical Pacific, which comprises the upward branch of the tropospheric Walker circulation. These cirrus shields will protect the lower stratosphere above from the upward flux of infrared radiation emitted by the warm atmosphere and ocean beneath. This is not true in the eastern tropical Pacific, where the air is generally much clearer. The pattern in the lower stratosphere of heating in the east and cooling in the west is hypothesized to lead to a "mirror-image" Walker circulation, as implied by the radar observations of vertical velocities. The measurements of methane, ozone and water we propose from the Global Hawk will allow this concept to be tested during a single flight. The presence of longitudinally varying gradients on the scale of the Pacific basin would have important implications for models of the general circulation, and for how injection of air into the stratosphere is viewed.

- **Particle production.** It has been shown [*Brock et al.*, 1995] that particle production occurs at the tropical tropopause, based upon a limited number of ER-2 profiles taken during the ASHOE-MAESA project (**Figure 2.1-2**). The details of the mechanism, however, and its possible relationship to cloud processes remain unclear. The effect of recirculation on particle formation may be important, and we expect the correlations we will obtain along the long flight tracks of the Global Hawk over regions of ascent and descent on many scales in the Pacific basin to be informative in this respect.

- **Tropical dynamics.** The Quasi-Biennial Oscillation (QBO) of the equatorial lower stratosphere, first noted by *Reed et al.* [1961] and *Veryard and Ebdon* [1961] is a much studied phenomenon, but historically poorly modeled in free running general circulation models. However, recent attempts at resolutions that allow generation of equatorial gravity waves are making progress [*Horinouchi and Yoden*, 1998; *Takahashi*, 1999]. Gravity waves were found to be an important component of the forcing required for a realistic simulation. *Dunkerton* [1997] noted that as model resolutions improve, eventually all scales of motion relevant to the QBO may be explicitly simulated. However, at the present, parameterizations are still required. *Pfister et al.* [1993a,b] have shown it possible to infer gravity wave momentum fluxes with aircraft measurements of temperature, pressure and winds, similar to those proposed with the Global Hawk. Although presently radiosonde estimates of gravity wave properties [*Sato and Dunkerton*, 1997] are used to characterize convectively generated waves, measurements across the entire Pacific basin will be quite valuable in producing characterizations valid on global scales.

- **Scale invariance.** Recently, it has been discovered that total water, ozone, methane, wind and temperature were scale invariant in the upper troposphere, at the tropopause, and in the lower stratosphere during WB-57F flight tracks south from Houston (30˚N, 95˚W) to inner tropical latitudes in the range 5˚N to 12˚N [*Hovde et al.*, 2000]. **Figure 2.1-3** provides an example for water, ozone, wind speed, and temperature. This result is consistent with the fractal behavior (power law scaling) demonstrated earlier during NASA ER-2 flights in the extratropical lower stratosphere, extending from scales as long as one Earth radius down to a few hundred meters. The physical significance of scale invariance lies in the accompanying long-

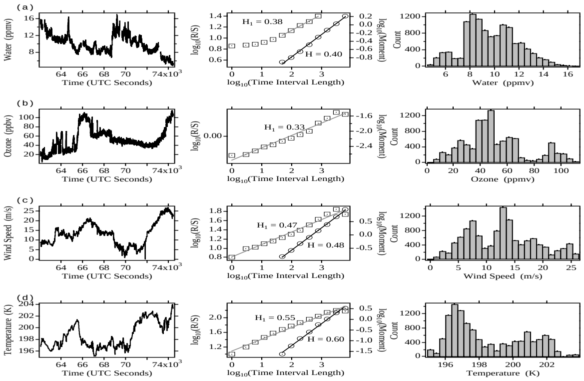

Figure 2.1-3. Scaling behavior for total water, ozone, wind speed and temperature, taken from the WB-57F on the same flight as **Figure 2.1-1**. The traces are in the left hand column, the corresponding log-log plot is in the middle column, and the frequency distribution is in the right hand column. Linearity in the log-log plot indicates scale invariance, with an associated asymmetric histogram. The departure from linearity at about 6 s in the top row indicates that instrument noise and atmospheric variability have become equal for total water on that time scale.

tailed probability distributions of variables along horizontal flight tracks; there is an implication that all scales are involved in the maintenance of the mean state, with substantial contributions from relatively infrequent, high amplitude events. The unique capability of the Global Hawk as regards long flight tracks should enable the examination of the scale invariant behavior towards the longest scales on which it might occur - it cannot be longer than half an Earth circumference, or 180 great circle degrees. We anticipate continuous flight segments as long as 100 great circle degrees (11,000 km). The scale of these segments will also overlap with larger scales that are resolvable by both satellite observations and by global numerical models. The benefits from this natural complementarity should be significant to all three approaches in that the *in situ* results from the Global Hawk will be set in a larger context, the global approaches will know "what they are averaging over." The tests [*Hicke et al.*, 2000] of a mesoscale model made using fractal methods during a WB-57F flight through mountain waves from the Rockies (**Figure 2.1-4**) could thus be extended to much larger scales at low latitudes, and may offer valuable clues as to how to approach the representation of small scales in global models.

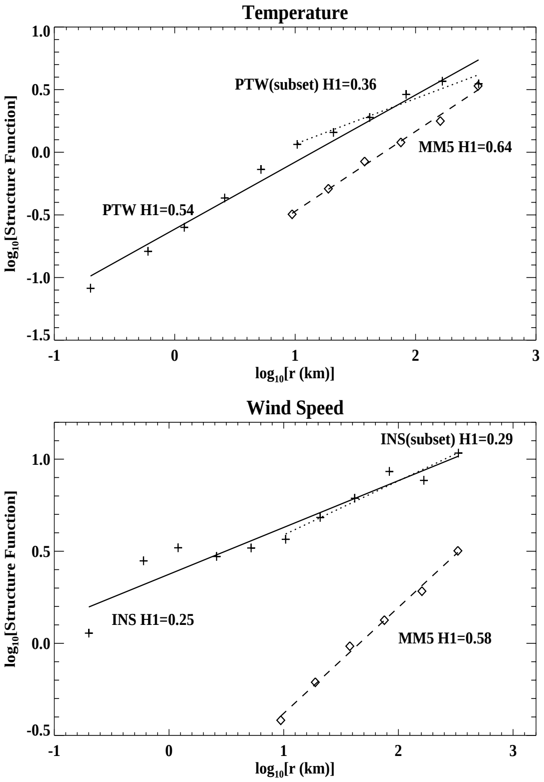

Figure 2.1-4. Comparison of flight data with the MM5 model. Data are from the 11 April 1998, WB-57F flight of WAM over northern Wyoming, U.S.A. Log-log plot of interval distance versus structure function used in calculation of *H*1, a measure of persistence (0 indicates antipersistence or noisy data, 1 indicates persistence or smooth data). (a) Observed temperatures (plusses; solid line) and interpolated MM5 modeled (diamonds; dashed line) temperatures. (b) Wind observations (plusses) and interpolated MM5 modeled (diamonds) horizontal wind speeds. Least squares fits also plotted. Dotted line indicates fit to observation structure functions using only MM5 scales. Note that the MM5 modeled data are smoother than the observations. From *Hicke et al.,* 2000.

2.2 Science Objectives

The GHATTEX data set and its interpretation will contribute to the following science objectives:

- Establish the distribution of water, cirrus, aerosols, ozone, carbon dioxide and methane in the tropical UT/LS on the scale of the Pacific basin.
- Understand, through analysis, modeling, and use of satellite data, the maintenance of these distributions from dynamical and radiative standpoints.
- Test the hypothesis that the interplay between deep convection and adiabatic transport from mid-latitudes is a major mechanism in the maintenance of the tropical tropopause.
- Examine the extent to which interhemispheric asymmetries in chemical composition are linked to the ITCZ.
- Observe evidence for recirculation of air between the tropical troposphere and stratosphere.
- Test the hypothesis that there is a "mirror-image" Walker Circulation in the lower stratosphere over the tropical Pacific.
- Make observations to further explore particle production at the tropical tropopause.
- Extend the horizontal scales upon which fractal behavior (power law scaling, scale invariance long-tailed probability distribution functions) in the tropical UT/LS was observed by the NASA ER-2 and

WB-57F aircraft by a factor of four and combine the overlapping spatial scales with satellite data to understand the processes at work.

- Observe convectively generated, tropical gravity waves with long, horizontal wavelengths and attempt to estimate their contribution to the momentum budget of the tropical lower stratosphere.
- Use tracer observations coupled with transport models to examine mixing processes and bulk transport into and within the tropical lower stratosphere.

2.3 Scientific Capability of the Payload

The methane observations reveal significant atmospheric structure in level flight on the WB-57F at 50,000 ft in the upper tropical troposphere. This structure can be correlated in a consistent manner with structure in ozone and with the chemical composition of individual aerosol particles. High methane appears to be a marker for near surface air. Correlation with water near the tropical tropopause provides powerful insight into how processes there affect the total hydrogen budget in the stratosphere above, an important issue for both chemistry and circulation there.

Ozone is an essential measurement near the tropopause, because it is a tracer there and because it is radiatively important. It also initiates much of the photochemistry via its photodissociation to produce reactive, excited oxygen atoms.

Carbon dioxide is an important molecule in the radiation balance of the atmosphere, and has also been demonstrated to be a useful tracer in the UT/LS [*Boering et al.*, 1996]. The interhemispheric gradient in the troposphere can be transported to the stratosphere, for example, and there is also a seasonal variation in the troposphere, particularly in the Northern Hemisphere.

Total water corresponds to water vapor in the absence of cirrus clouds, and to the sum of water vapor and vapor from evaporated ice crystals in their presence. Its measurement is central to any computation of the radiative balance, and in the interpretation not only of the effects of deep convection but also in the interpretation of the data from the particle sizing instruments. The degree of dryness of the lower stratosphere is also an important observation, and by extension its correlation with methane. Methane is lost photochemically in the middle and upper stratosphere, leading to less than tropospheric abundances in the lower stratosphere.

Aerosol particles are important because they may affect radiative transfer directly, and indirectly if they are capable of acting as condensation nuclei to form ice crystals (cirrus) which can have large effects upon both solar and terrestrial radiation. The discovery that they are produced at the tropical tropopause [*Brock et al.*, 1995] adds interest, particularly in view of evidence from NASA ER-2 flights that recirculation of air between the upper troposphere and lower stratosphere occurs, and from NASA WB-57F flights that the aerosol content of mercury and organics near the tropical tropopause is unexpectedly high.

Cirrus ice particles may range from a few to many tens of microns in size, and may have very complex effects on both UV/visible and upon infrared radiation. When they grow large enough, their gravitational sedimentation leaves behind dehydrated air masses, a mechanism which is certainly important in the entry of air to the stratosphere in the inner tropics. The maintenance of cirrus sheets in the upper tropical troposphere poses some important questions [*Boehm et al.*, 1999]. Subvisible cirrus is important in the 1 to 2 km below the tropical tropopause, both radiatively and as a possible player in the dehydration of air entering the stratosphere. Microphysical modeling suggests that the maintenance of subvisible sheets for long times and on long scales may entail upwelling on those scales [*Boehm et al.*, 1999; *Sherwood*, 1999]. Our payload will be able to examine this phenomenon using MASP cirrus observations and tracer correlations.

The temperature profiles above and below the aircraft are of vital importance to the mission science. The tropopause is accurately located while in horizontal flight, and structures from gravity waves on scales of hundred meters to scales on the length of the flight track are revealed, with vertical resolution of typically 100 m near the aircraft and 700 m a scale height away. An example, filtered to highlight gravity waves, is shown in **Figure 2.3-1**.

Temperature and pressure measurements are fundamental both to the science and to the operation and data analysis of the other instruments. The temperature will be recorded at 50 Hz, and in conjunction with horizontal winds from the aircraft’s GPS navigation system at the same frequency, will allow these variables to be recorded at length scales as short as 3.5m, easily short enough for the scale invariance

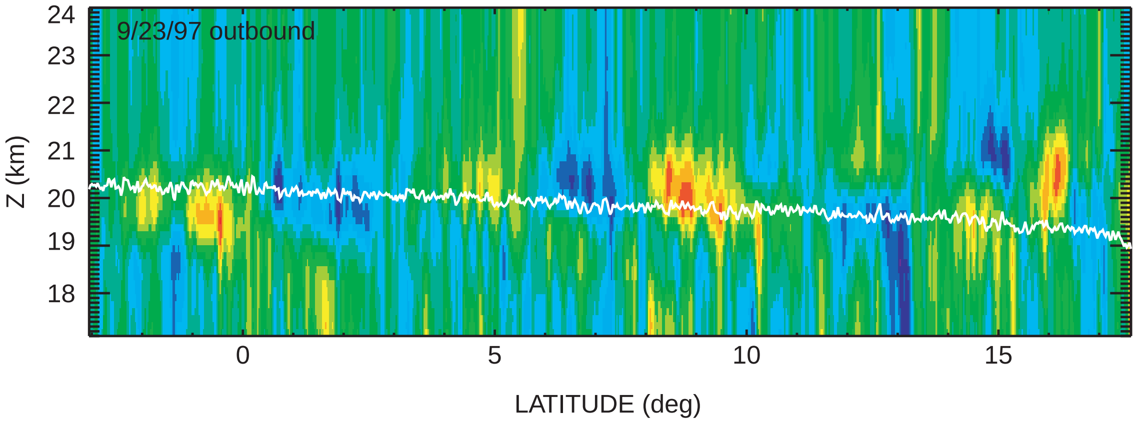

Figure 2.3-1. Temperature perturbations as a function of flight path latitude and altitude as measured by the MTP instrument flying on the NASA ER-2 aircraft in the stratosphere. The flight occurred on September 23, 1997, originating in Barbers Point, HI. Color indicates the temperature deviation from a 500-km running mean computed separately at each height. Peak perturbations are 5K. The white line shows the aircraft flight path.

analysis to be extended to those at which three-dimensional Kolmogorov turbulence theory should apply. The scale invariance software has been used to distinguish noise from atmospheric variability in time series of the NASA ER-2 and WB-57F data records.

Collectively, the GHATTEX payload is more than the sum of its parts. It will measure all categories of physical properties - gaseous, aerosol and solid – which affect radiative transfer. The water, tracers, ozone and aerosols will allow much dynamical inference on a very wide range of scales, and will be revealing about how variations in chemicals correlate as a function of scale.

2.4 Relation to Office of Earth Science Research Themes

- ***Theme 2, Global Water and Energy Cycle***

Is the cycling of water through the atmosphere accelerating? There is a recently reported trend in tropical tropopause cold point temperatures [*Simmons et al.*, 1999], and a longer-standing and recently extended trend in the water vapor content of the lower stratosphere at northern mid-latitudes [*Harries*, 1976; *Oltmans and Hofmann*, 1995].

Satellite data also suggest "trends" over the last nine years in the total hydrogen content of the middle and upper troposphere [*Evans et al.*, 1998]. Our flights will investigate the mechanisms that might cause such behavior, on scales ranging from 200 m to 11000 km.

How can the integrated effects of fast atmospheric, land and ocean surface processes be accurately included in large scale climate models? The scale invariance in water and meteorological variables, which also exists for ozone and methane, extends over NASA ER-2 and WB-57F tracks from 200 m up to the longest observed scales of 2800 km. The Global Hawk will extend this scale to 11,000 km over the Pacific basin, and for winds and temperature will yield observations on a scale of 3.5 m. This will permit a test of Kolmogorov turbulence theory, and allow examination of the atmosphere for a scale break marking a transition between 2D and 3D turbulence. Scale invariance implies fractal geometry and long-tailed probability distributions. Because fractal geometry employs a complicated building block (as observed) with a simple algorithm (power law scaling) to describe the morphology of a convoluted object, it may have important implications for the representation of processes as a function of scale in large-scale climate models. Hicke *et al.* [2000] have shown that the MM5 mesoscale model, for example, does not produce the power law scaling observed from the WB-57F (**Figure 2.1-4**). The Global Hawk will extend such a test to the scales simulated by GCMs. Scale invariance may imply that parameterization by diffusive formulations at scales below the grid size has fundamental limitations.

- ***Theme 3, Climate Variability and Prediction***

Can the observed climate trends be attributed to a specific factor? This is of course a very complicated, multivariate problem. Nevertheless, as noted in Theme 2 above, it is possible that we may find mechanisms to explain the increase in stratospheric water vapor. The water vapor content of the lower stratosphere has been shown to be radiatively important [*Forster and Shine*, 1999], and hence may play a role in climate trends. Climate trends may also be affected by ozone decreases related to subtropical jet stream dynamics [*Reid et al.*, 2000].

Can current global climate variations be understood and predicted? Climate variability is believed, on the basis of numerical modeling and some limited observations, to be affected both by trace gases (particularly those which absorb in the 7- to 14-μm window) and by aerosols. The proposed Global Hawk payload will make direct observations of water vapor, ozone, carbon dioxide, methane, aerosols and cirrus in a crucial region, the UT/LS in the Pacific basin. We expect to investigate this on a very wide range of scales by interpreting and comparing model results.

• *Theme 4, Atmospheric Chemistry*

How will stratospheric ozone respond to the reductions in atmospheric abundance of ozone-destroying industrial chemicals? It has been established that only ~10 to 15% of the air rising in the inner tropics at ~100 hPa continues through ~50 hPa to populate the "overworld" [*Rosenlof et al.*, 1997]. Our results will help address the consequence of this for short-lived industrial compounds and aerosols in the stratosphere. It has also been established that there has been an increase over the last 30 years in the frequency of transport from the upper tropical troposphere across the subtropical jet stream into the lower stratosphere of northern mid-latitudes, accounting for up to 30% of the observed ozone loss there by the direct effect of the associated dilution [*Reid et al.*, 2000]. Our flights will throw further light on this mechanism.

How does the chemistry of atmospheric trace constituents respond to and affect climate? If the suggestion that the maintenance of the tropopause is importantly influenced by the adiabatic exchange of air between the tropics and mid-latitudes is correct [*Hovde et al.*, 2000], the way is open for the operation of an interactive coupling between chemistry and climate. Ozone heating is an important element in the radiative balance at the tropopause; a rise in tropopause height of only 5 to 10 m a year could make a very significant contribution to the observed mid-latitude ozone loss [*Hoinka*, 1998]. The examination of the chemical composition of the UT/LS in the subtropics and tropics on very long scales will address the mechanisms at work in the Pacific basin, where much of the ascent is believed to occur.

3.0 Science Plan

GHATTEX seeks to demonstrate how measurements from a long endurance, high-altitude UAV such as the Global Hawk can be used to examine a remote region of the upper troposphere and lower stratosphere (UT/LS) over the tropical Pacific basin. GHATTEX will examine the composition of this region with detailed, high-frequency observations of meteorological, radiative and chemical importance. The observations will be made with a payload of established, well-calibrated sampling instruments linked with satellite data and atmospheric model results to place them in a broader scientific context. GHATTEX specific science objectives are listed above in **Section 2.2** and the proposed payload instruments are listed in **Section 2.3**.

3.1 Project Requirements IP-Section 2.1

The GHATTEX science objectives place a number of critical requirements on the instruments used, the makeup of the assembled team, and the aircraft performance. In addition, project cost effectiveness must be taken into account. A summary of the specific requirements for GHATTEX are as listed below. This proposal and the attached Implementation Plan confirm how these project requirements are being or will be met.

- *Scientific Instrument Requirements.* The collective requirements imposed on the instruments include the following:
  - must address one or more of the GHATTEX science objectives;
  - must be certified safe for flight in the expected environments;
  - must be configured to operate in an autonomous mode;
  - must have sufficient reliability to ensure data are acquired throughout the long flights;
  - must have sufficient accuracy and precision to ensure that the data are of scientific quality;

  - must fit within the volume, weight and power available on the aircraft;
  - must output sufficient status information for the aircraft to ascertain the health of the instruments; and
  - must allow the aircraft control system to power the instruments on and off during flight.
- *Project Team Requirements.* The most critical requirement for project success is the demonstrated ability of the key personnel associated with the project to provide and operate the payload instruments and to scientifically interpret the acquired data set. This requirement implies that the principal investigators must have experience with high-altitude aircraft missions, that the instrument PIs have flown the selected or similar instruments, and that the theory team be well-versed in the theoretical and modeling aspects related to flight planning and in the interpretation of the expected data sets.
- *Aircraft Performance Requirements.* The minimum performance requirements of the aircraft are defined by the particular project objectives. For GHATTEX, these include:
  - service ceiling in excess of 60,000 ft. (18 km);
  - minimum unrefueled radius-of-action of 5000 nautical miles (9260 km);
  - payload capacity in excess of 1000 lbs (450 kg) and volume of 17 cu. ft (0.48 m^3);
  - minimum of 5 kW of electrical power;
  - sufficient reliability to ensure project success; and
  - a well-defined process for conducting safe flight operations.
- *Operational Requirements*
  - mission safety verified by reviews;
  - schedule certainty provided by well-defined procedures for integration and operation of the instruments on board the UAV;
  - laboratory facilities to support the deployment team; and
  - demonstrated performance by the aircraft in areas similar to the GHATTEX deployment areas.
- *Education and Public Outreach Activities.* The EPO activities chosen to provide access to GHATTEX activities are:
  - Internet website;
  - teacher-scientist partnerships;
  - media relations; and
  - EAFB Open House.

3.2 Project Concept IP-Section 2.1.2

The GHATTEX Project consists of four major components: the Project Team, the Instrument Payload, the Global Hawk UAV Platform, and Education and Public Outreach activities. Each of these components is briefly described below.

• *Project Team.* The GHATTEX Project Team includes technical support and scientific members (see **Table 3.2-1**). Dr. Adrian Tuck will act as the project leader and, along with Dr. David Fahey, will be involved in all aspects of the project. In addition, Dr. Gerhard Hübler will perform project coordination and technical support in order to assist Dr. Tuck and Dr. Fahey in the project management. Each instrument has a science and support team based at the instrument home institution and lead by an Instrument PI as listed in **Table 3.2-1**. The Science Team includes the Instrument PIs and their associated teams, and several other investigators leading theoretical and modeling aspects related to flight planning and the interpretation of the expected data sets. The NG-RAC point-of-contact is Mr. Greg Loegering, a senior staff engineer associated with the Global Hawk program from its inception. In addition to Mr. Loegering, the GHATTEX support team from NG-RAC includes design engineers, project leads, and flight test personnel as required. The point-of-contact for the USAF, the provider of the Global Hawk UAV, will be 1st Lt Adam Wehner of the Global Hawk Special Projects Office at Wright Patterson AFB. A short curriculum vita is attached in **Appendix D** for each participant listed in **Table 3.2-1**.

Table 3.2-1 GHATTEX Project Team **IP-Table 2.1-1**

Participant or PI	**Institution**	**Activity**
Project PI		
Dr. A. F. Tuck	NOAA Aeronomy Laboratory, Boulder, CO	Project PI
Dr. D. W. Fahey	NOAA Aeronomy Laboratory, Boulder, CO	Project Co-PI
Instrument PI		
Dr. B. W. Gandrud	Particle Metrics, Inc., Boulder, CO	Ice particles (MASP)
Dr. R. S. Gao	NOAA Aeronomy Laboratory, Boulder, CO	Carbon dioxide
Mr. K. K. Kelly	NOAA Aeronomy Laboratory, Boulder, CO	Water vapor
Dr. M. J. Mahoney	NASA Jet Propulsion Laboratory, Pasadena, CA	Temperature (MTP)
Dr. E. C. Richard	NOAA Aeronomy Laboratory, Boulder, CO	Ozone and methane
Mr. T. L. Thompson	NOAA Aeronomy Laboratory, Boulder, CO	Temperature and pressure, and GPCC computer
Prof. J. C. Wilson	University of Denver, Denver, CO	Small particles (FCAS/NMASS)
Theory PI		
Dr. M. J. Alexander*	NorthWest Research Associates, Colorado Research Associates Division, Boulder, CO	Data interpretation
Prof. R. A. Plumb	Massachusetts Institute of Technology, Boston, MA	Data interpretation
Dr. K. H. Rosenlof	NOAA Aeronomy Laboratory, Boulder, CO	Meteorological support
Prof. M. H. Hitchman**	University of Wisconsin-Madison, Madison, WI	Data interpretation
Prof. R. E. Newell**	Massachusetts Institute of Technology, Cambridge, MA	Data interpretation
Prof. D. W. Waugh**	Johns Hopkins University, Baltimore, MD	Data interpretation
Project Support		
Ms. S. J. Hovde	NOAA Aeronomy Laboratory, Boulder CO	Data archive support
Mr. G. Loegering	Northrop Grumman Ryan Aeronautical Center, San Diego, CA	Global Hawk integration and operations
Mr. R. H. Winkler	NOAA Aeronomy Laboratory, Boulder CO	Instrument control and payload data acquisition
Dr. G. Hübler	NOAA Aeronomy Laboratory, Boulder CO	Mission coordination and technical support
1st Lt A. Wehner	USAF ASC/RAV, Wright Paterson AFB, OH	Global Hawk provider representative
Education outreach		
Dr. S. Buhr	Cooperative Institute for Research in Environmental Sciences, Univ. of Colorado, Boulder, CO	Coordinate student and teacher outreach activities

* Funded separately by the National Science Foundation
** Funded separately by NASA's Atmospheric Chemistry Modeling and Analysis Program (ACMAP)

- *Instrument Payload.* The GHATTEX payload consists of eight instruments and the GHATTEX Payload Control Computer (GPCC) (see **IP-Table 2.1-2** and **Figures 3.2-1**, **3.2-2**, and **3.2-3**). Descriptions of each instrument are included in **IP-Section 2.1.2.1**. All instruments have participated in airborne sampling except the CO_2 instrument being constructed as part of this project. The CO_2 instrument design will be based on a proven NOAA Aeronomy Laboratory CO_2 instrument in use on the NOAA WP-3D aircraft. Seven of the eight instruments comprising the GHATTEX payload have been operated in unpressurized spaces at altitudes up to 68,000 ft on the NASA ER-2 and WB-57F subsonic research aircraft, for flight durations of up to 8 hours. Thus, these seven instruments have already been flight qualified to operate in the environments expected in the UAV. The eighth, the CO_2 instrument, will be built during the GHATTEX pre-deployment phase by NOAA/AL. An existing NOAA/AL CO_2 instrument operates on the

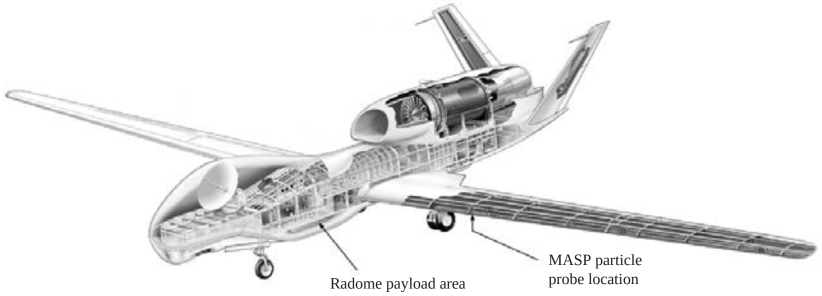

Figure 3.2-1 Schematic of the Global Hawk UAV showing the GHATTEX payload areas. All instruments except MASP aerosol probe will be located in the SAR radome below the forward fuselage. MASP will be mounted under a wing.

NOAA WP-3D aircraft in flights reaching up to 24,000 ft for up to 10 hours. This instrument has participated in a regular series of NOAA research flights addressing air quality in the troposphere.

All instruments in GHATTEX will operate completely autonomously and record data with on board digital storage media. Power and communication to the instruments will be handled by the GPCC. The GPCC will also record instrument status and some instrument data in order to provide redundancy for the instrument data recording systems.

• *Global Hawk UAV Platform Description.* The Global Hawk UAV is the only currently available UAV that can be used to meet GHATTEX flight and payload objectives. The Global Hawk has been developed for the U.S. Air Force by the Ryan Aeronautical Center of the Northrop Grumman Corporation (NG-RAC).

Global Hawk, which first flew in February 1998, is a jet-powered aircraft with a conventional aluminum fuselage and graphite composite wings and appendages (see **Figure 2.1-2**). The aircraft is 44.4 ft. long, 15.2 ft. high, and has a wingspan of 116.2 ft. Fully loaded with fuel, the aircraft has a maximum take-off gross weight of 25,800 pounds. The maximum estimated range of the aircraft is 11,040 nautical miles (20,500 km or 0.5 of the Earth's circumference) at Mach 0.6 with an endurance of 32.6 hours to start of landing descent.

The maximum operating altitude is 65,000 ft. The current payload capacity is near 1500 pounds, and currently consists of an integrated synthetic aperture radar (SAR) and electro-optic/infrared reconnaissance payload. In addition, the aircraft can provide up to 6.2 kVA of AC power, up to 2.95 kW of DC power, and has been certified for operation at temperatures down to -77ºC. GHATTEX will use only about 50% of the payload mass, volume, and power capacities of Global Hawk.

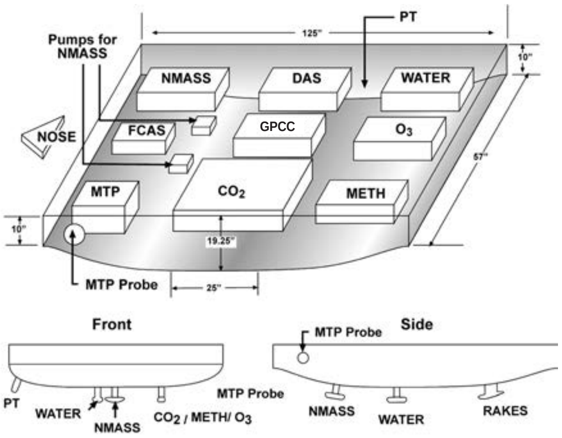

Figure 3.2-2 Schematic of the location of the GHATTEX instruments in the SAR radome payload area. The direction of the Global Hawk nose and dimensions are indicated in the figure. The instruments correspond to the payload list in Table 2.1-2 where METH indicates methane, and DAS indicates the MASP (ice particles) data acquisition system. Small particles are measured with the combination of FCAS-III and NMASS instruments. The FFS is shown in front and side views in the lower part of the figure. Schematic inlet and exhaust probe locations are indicated on the FFS. The Pressure and Temperature probe instrument is represented by the 'PT' designation on the FFS.

The Global Hawk has been designed to fit seamlessly into the national airspace system. It has standard mode 3/A and mode C transponders, and a satellite communication relay that allows the command and control operator (CCO) to talk to ATC over VHF and UHF radio even though the CCO is hundreds of miles away in the command and control shelter. It currently operates out of Edwards Air Force Base (EAFB) (co-located with NASA Dryden Flight Research Center) for the U.S. Air Force by Ryan Aeronautical under an FAA issued certificate of authorization.

- *Education and Public Outreach Activities*. The GHATTEX project provides an opportunity for students, teachers, and the public to learn about scientists' efforts to understand Earth's atmosphere in remote regions and to learn about a unique airborne platform that facilitates access to the atmosphere. Education and Public Outreach (EPO) activities will include several components. A website will be set up and maintained to provide access to GHATTEX information, images, schedules, and input from GHATTEX scientists and interested teachers. Partnerships between teachers and GHATTEX scientists will allow teachers improve their knowledge of the atmosphere and contemporary research efforts. Media contact will be made to distribute press releases regarding GHATTEX activities and announce the availability of educational material. An Open House will be conducted at EAFB for the public to view the aircraft and some GHATTEX instrumentation and to contact scientists. The GHATTEX EPO plan includes rigorous and complete formative and summative evaluation. The EPO team has extensive experience in designing and implementing evaluation of similar programs.

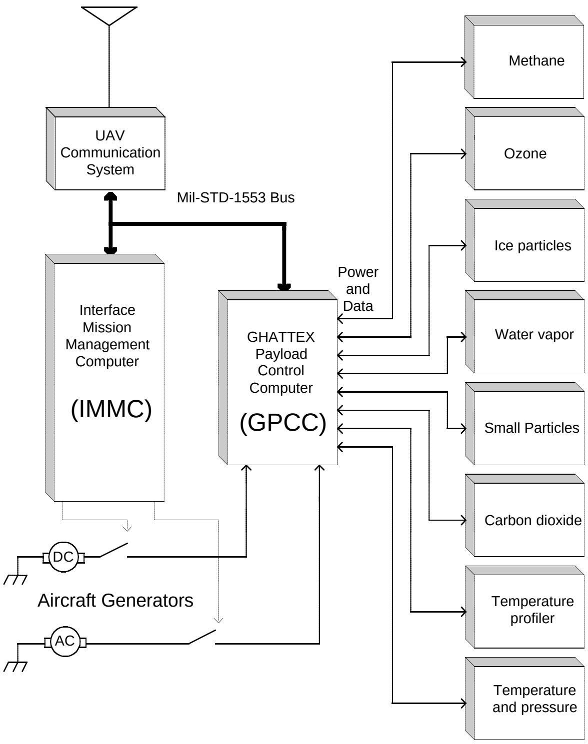

Figure 3.2-3 GHATTEX Payload Control Computer (GPCC) configuration. The IMMC and UAV Communication System are part of the Global Hawk aircraft system. The GPCC will control power and communication connections to the GHATTEX payload instrument suite with commands sent by the IMMC.

3.2.1 GHATTEX Alternatives Considered *IP-Section 2.2.1*

Alternative scientific goals, flight plans and payloads were considered in developing GHATTEX. Among them were deployments to a Southern Hemisphere location to study the Antarctic ozone hole, a deployment to EAFB to study Arctic ozone loss at high northern latitudes, and a deployment from EAFB to circumnavigate the Earth at the equator at altitudes near the tropical tropopause.

The polar missions would have necessitated payloads involving larger and heavier instruments. These would have added more expense to deploy, and in some cases would have conflicted with the USAF condition that any modifications to the aircraft must be rapidly reversible. For example, we would like to have included the Particle Analysis by Laser Mass Spectrometry (PALMS) instrument to investigate both polar stratospheric clouds and tropical aerosol and cirrus, but it is designed to fit the WB-57F nose; redesign of the instrument to fit the Global Hawk would have cost $1 to 2M and taken 1 to 2 years, thus eliminating it as an option. Therefore, since the PALMS would require a substantial re-design, and the deployment costs to Argentina or Chile would have been prohibitive at about $3M, the polar missions were no longer attractive. Additionally, the deep and extensive regions of very cold temperatures (less than -77°C) in the polar vortices would have necessitated certification of the Global Hawk for operation in lower temperatures, with a probable cost that would have been prohibitive in the context of the NRA. Finally, a circumnavigation experiment would require a deployment to an equatorial site about 180° longitude away from that of EAFB (120°W). The costs of such a deployment would have been approximately $3M, a cost that eliminated this experiment from consideration.

The GHATTEX payload of chemical, microphysical and meteorological instruments form a comprehensive, synergistic suite for this UAV demonstration project. A number of other instruments could substantially enhance the scientific return from the GHATTEX flights. Four examples are cited here; namely, an airborne gas chromatograph, a whole air sampler, an interferometric, high-spectral resolution radiometer covering the spectral range from the near to the far infrared, and a water vapor and aerosol lidar system. A two-channel airborne gas chromatograph measuring several long-lived gases has been successfully flown on a balloon and the WB-57F aircraft by Dr. J. Elkins of NOAA Climate Monitoring and Diagnostics Laboratory. A water vapor and aerosol lidar system has been designed and built for the Perseus UAV in cooperation with Dr. E. Browell of NASA Langley Research Center. One or more of these instruments could be accommodated easily in the forward fuselage payload area of the Global Hawk with additional instrument and science team costs of about $**** per instrument.

3.3 Global Hawk Advantages

The overriding advantage of the Global Hawk platform is its ability to carry a substantial payload of autonomous instruments on flight tracks spanning the Pacific tropical basin. It is the *only* aircraft that is capable of doing this at the requisite altitudes near the tropical tropopause, and that also meets the NASA NRA requirement of no substantial development. Accordingly, this aircraft was chosen as the project platform. No other aircraft, inhabited or uninhabited, meets or exceeds the Global Hawk's combined specifications of altitude, range, and payload capacities. In addition, the Global Hawk is compatible with the national and international airspace infrastructure and is a reliable and well-supported UAV platform.

- *Altitude, range, and payload.* The maximum operating altitude of the Global Hawk is 65,000 ft., the maximum estimated range is 11,040 nautical miles with an endurance of 32.6 hours to start of landing descent, and the current payload capacity is near 1500 lbs. The aircraft can provide up to 6.2 kVA of AC power, up to 2.95 kW of DC power, and has been certified for operation at temperatures down to -77ºC. (See **Section 3.2, IP-Section 2.0, IP-Table 2.3-1**). Although both the ER-2 and the WB-57F aircraft can meet the GHATTEX payload and altitude requirements, the operational, unrefueled radius-of-action of these aircraft is only 1500 nautical miles.

- *Airspace management.* The Global Hawk has been designed to operate in both national and international airspace. Global Hawk flights (see next paragraph) include those over the U.S.A., the Pacific Ocean, and the Atlantic Ocean. Airspace management issues are discussed further in **Section 4.5** and **IP-Section 2.7**.

- *Flight-proven capabilities.* Global Hawk has undergone an extensive series of taxi and flight tests to establish its flight envelope, as well as successfully completing its military-utility assessment test phase. As of January 2001, the Global Hawk fleet has accumulated a total of 759.1 flight hours in 65 flights. These include flights from EAFB to Alaska and back, a deployment to Eglin AFB in Florida, and one flight to Portugal and back (see **IP-Appendix D**). Flight duration exceeded 20 hours in 14 flights, while the maximum flight duration was 31.5 hours. (Global Hawk now holds the official world record for endurance of a jet-powered aircraft.) Maximum flight altitude exceeded 60,000 ft on 40 flights with an overall maximum altitude of 66,400 ft. Most flights carried full USAF sensor payloads (1500 lbs), and many operated outside the restricted airspace of EAFB. The duration, altitude, and location of the Global Hawk flights have demonstrated the aircraft performance and operations necessary to achieve GHATTEX objectives. Furthermore, these test and mission flights demonstrate that issues of flight safety (see **IP-Section 2.6**) and airspace management (see **IP-Section 2.7**) have been handled successfully.

Future USAF flights are planned to the equator at longitudes of 95° to 125°W during northern winter 2000/2001 and to Australia during the spring of 2001. These proposed flight tracks are very similar in part to the proposed GHATTEX flight tracks (see **Section 4.3**) and consequently will add relevant Global Hawk experience for meeting GHATTEX flight objectives.

- *Support.* The Global Hawk UAV was developed and is supported by its provider, the U.S. Air Force (USAF), and the manufacturer, Northrop Grumman Ryan Aeronautical Center (NG-RAC). GHATTEX will take advantage of this extensive infrastructure and experience already in place for the Global Hawk. The USAF at WPAFB will work directly with NOAA/AL and NG-RAC to achieve the GHATTEX payload integration and flight objectives. In addition, Colonel Wayne M. Johnson, of the Global Hawk Systems Program Office at WPAFB has formally supported the use of the Global Hawk in GHATTEX in a letter to the Project PI received 28 February 2001 (see **Appendix C)**. This letter is an update of the commitment received from Colonel Robert E. Dehnert, Jr., dated 3 May 2000. GHATTEX is the only external Global Hawk project to be approved by the USAF from many requests. Mr. Norm Sakamoto of NG-RAC (Vice

President, New Business Development, Global Hawk) has also written an updated letter of support (see **Appendix C**), thus providing the requisite contractor support required by the NRA. Funding for Global Hawk activities will be transferred to USAF WPAFB and managed along with other tasks within their Global Hawk Systems Program Office. GHATTEX funding will also be provided to the USAF 452nd FLTS through WPAFB to support Global Hawk flight operations at EAFB.

3.3.1 Collier Award

The Global Hawk has received the 2001 Collier Award from the National Aeronautic Association. The award is presented annually for ‘the greatest achievement in aeronautics or astronautics in America, with respect to improving the performance, efficiency, and safety of air or space vehicles, the value of which has been thoroughly demonstrated by actual use during the preceding year’ (see http://naa-usa.org/website/html/newsset.html.). Northrop Grumman will accept the award at a meeting of the National Aeronautical Association in May 2001.

3.3.2 Milestone II Approval

In addition to being selected as this year’s winner of the Collier Award, the Global Hawk program successfully obtained Defense Acquisition Board (DAB) milestone II approval for full engineering and manufacturing development (EMD), as well as approval for low-rate initial production (LRIP). This approval further ensures that the Global Hawk will be available to support the GHATTEX objectives.

3.4 Changes from Original Proposal

The science objectives and project strategy for obtaining those objectives have remained unchanged from the original proposal. The scientific aspects of the original proposal are reproduced in **Section 2.0**. The proposed scientific outcomes of GHATTEX are unchanged from the original proposal. In the GHATTEX schedule, the winter mission flights now occur before the summer mission flights as a result of the delay in start date from the original proposal.

3.5 Scope and Risk Mitigation

3.5.1 Scope Options *IP-Section 2.2.2*

Scope options will facilitate changing the project objectives during GHATTEX in the event of difficulty with meeting cost and schedule requirements. Because both the aircraft and the payload are well proven, many of the costs are associated with the salaries of the people who will perform the three main tasks: (i) instrument preparation and payload integration; (ii) test flights and science flights; (iii) data analysis and scientific research. Two principal scope options are:

- *Cancellation of the summer flight deployment.* The summer flight window begins 3.5 months after the winter flights in a separate deployment. Costs for the summer flights are primarily associated with aircraft operations and instrument and theory team participation. Because the cancellation would occur well in advance of the deployment, full costs for the deployment would likely be saved. If the winter flights were successful, then mission data would be available for scientific interpretation. Thus, a substantial fraction of the scientific objectives of GHATTEX would still be met without summer flights.

- *Reduction of the data analysis period.* The reduction of the data analysis period or the number of funded participants could be used to reduce costs in the final phase of GHATTEX. The costs of the theory and data analysis activities in year three are a significant fraction of the total proposal cost. The costs are spread over 10 investigator groups in 5 institutions. However, without the data analysis activities, there would be no scientific return from the mission flights. A substantial amount of data analysis will be done by NOAA/AL investigators who are funded directly from NOAA/AL’s *in-kind* contribution to GHATTEX. Thus, some data analysis will occur without NASA funds in year three. Some data analysis costs are being supported indirectly from ACMAP funds as directed by Dr. P. DeCola (per discussion in November 2000). ACMAP activity would involve Prof. M. Hitchman, Prof. R. Newell, and Prof. D. Waugh (see **Table 3.2-1**). Other sources within NASA could also be asked to support data analysis if GHATTEX support were not made available.

Cancellation of the summer science flights would truncate the schedule by 2 months, if this scope option were decided upon at the end of the winter flights. Exercising the option of canceling the last 6 months of the project (half the theory and data analysis) would shorten the entire project from 36 to 30 months.

The entire cost of the summer deployment would be saved if the scope decision were taken promptly after the winter flights. Cutting the last 6 months of the project would save approximately half the money budgeted for theory and data analysis, depending on exactly when the option was decided upon.

The total GHATTEX cost can be reduced to $**** by exercising the scope option to reduce the data analysis period. In the event that airframe #5 remains available for GHATTEX flights, the $**** cost reserve would then be used to restore the data analysis budget as presented in this proposal. The decision regarding the use of airframe #5 would be made early enough in the schedule to allow theory investigators to plan for the extended data analysis activity.

3.5.2 Risk Mitigation

Risk mitigation is discussed in **Section 5.5**.

3.6 Data Analysis, Archival, and Distribution Plan IP-Section 2.8

The basic data analysis, archival, and distribution plan for GHATTEX has not changed from the original proposal. The science team's theoretical capability however has been considerably enhanced by the addition of new team members. Prof. M. Hitchman (Univ. of Wisconsin), Prof. R. Newell (MIT), and Prof. D. Waugh (Johns Hopkins) will reprioritize current funding from NASA's Atmospheric Chemistry Modeling and Analysis Project (ACMAP) to analyze the GHATTEX data set. A letter of support for the reprioritization from Dr. Phil DeCola, ACMAP Program Manager is included in **Appendix C**. Travel funds for these investigators are included in the GHATTEX budget.

3.6.1 Data Analysis IP-Section 2.8.1

Data analysis with the archived GHATTEX data set will follow procedures and methods that have been used successfully in previous high-altitude aircraft missions. Most of the GHATTEX Instrument PI and Theory PI teams have substantial experience interpreting aircraft data sets of gases, particles, and meteorological parameters. Other interested theoretical investigators have been invited to collaborate with the GHATTEX Science Team in the interpretation process. These studies can be performed without the acquisition of new hardware or software. All investigators have adequate facilities for analysis activities.

Science objectives as delineated in the original proposal for GHATTEX are listed below, followed by a) key measurements needed, b) analysis methods, and c) responsible Science Team members. For successful analysis activities, it is imperative that the majority of the instruments function adequately for at least one of the two flights planned in each deployment.

- Establish the distribution of H_2O, cirrus, aerosols, O_3, CO_2 and CH_4 in the tropical UT/LS over the Pacific basin.
  a) All proposed measurements needed.
  b) Meteorological, statistical and visual analyses.
  c) D. W. Fahey will lead this activity, which will involve many Science Team members.
- Understand through analysis, modeling, and use of satellite data the maintenance of these distributions from dynamical and radiative standpoints.
  a) O_3, H_2O, temperature, pressure critical; other aircraft measurements useful. Satellite cloud (GOES, GMS, Aqua) and tracer (UARS, Terra, POES) measurements also useful.
  b) Radiative transfer, trajectory, and chemical modeling.
  c) R. A. Plumb and A. F. Tuck will lead this analysis activity, in collaboration with all other Science Team members.
- Test the hypothesis that the interplay between deep convection and adiabatic transport from mid-latitudes is a major mechanism in the maintenance of the tropical tropopause.
  a) Temperature, H_2O, O_3, aerosol distribution, cloud information from satellite.
  b) Radiative transfer modeling, trajectory modeling, tracer modeling.
  c) A. F. Tuck, R. A. Plumb, and M. Hitchman will lead this activity, with input from other investigators.

- Examine the extent to which interhemispheric asymmetries in chemical composition are linked to the ITCZ.
  a) Measurements crossing the ITCZ required, O_3 and CH_4 are critical, other measurements useful, satellite observations of cloud cover required.
  b) Statistical analyses.
  c) A. F. Tuck and R. E. Newell will lead this activity, with input from other investigators.
- Observe evidence for recirculation of air between the tropical troposphere and stratosphere.
  a) Need vertical profiles in the deep tropics of long-lived tracers (O_3, CH_4) and aerosols.
  b) Statistical analyses.
  c) A. F. Tuck and D. W. Fahey will lead the activity, with input from other investigators and guided by R. A. Plumb.
- Test the hypothesis that there is a “mirror-image” Walker Circulation in the lower stratosphere over the tropical Pacific.
  a) Temperature, pressure, H_2O, and O_3 required; CH_4 useful. Flight track crossing the equatorial Pacific needs be oriented in an E-W direction in the lower stratosphere. One such flight in each deployment is needed to assess seasonal differences.
  b) Examination of horizontal gradients of relevant species and temperature, radiative and transport modeling also will be performed.
  c) A. F. Tuck and D. W. Waugh will lead this activity with input from other investigators.
- Make observations to further explore particle production at the tropical tropopause.
  a) Aerosol, temperature, pressure, and H_2O critical. Upper troposphere and lower stratosphere measurements on or near the Equator required.
  b) Statistical analyses and aerosol production modeling.
  c) J. C. Wilson will lead this activity.
- Extend the horizontal scales in the tropical UT/LS upon which fractal behavior has been observed by a factor of four and combine the overlapping spatial scales with satellite data to understand the processes at work.
  a) O_3, temperature, CH_4, H_2O critical, other aircraft measurements useful.
  b) Compute probability distribution functions (PDFs) and fractal indices for individual flights, and examine statistics over all flights.
  c) A. F. Tuck, E. C. Richard, and S. J. Hovde will lead this activity, aided by R. E. Newell.
- Observe convectively generated, tropical gravity waves with long, horizontal wavelengths and estimate their contribution to the momentum budget of the tropical lower stratosphere.
  a) MTP measurements taken over long flight tracks at a single level in the lower stratosphere, flight level temperature and navigational horizontal winds needed.
  b) Spectral analysis and gravity wave modeling
  c) M. J. Alexander and M.J. Mahoney will lead this activity.
- Use tracer observations coupled with transport models to examine mixing processes and bulk transport into and within the tropical lower stratosphere.
  a) Pressure, temperature, O_3, and CH_4 critical, meteorological analyses also required.
  b) Statistical analyses, trajectory modeling, tracer-tracer mixing modeling and chemical modeling.
  c) R. A. Plumb, K. H. Rosenlof, and D. W. Fahey will lead this activity.

3.6.2 Quality Assurance Approach *IP-Section 2.8.2*

Data used in the GHATTEX interpretive studies need to be highly accurate and precise. Individual instrument investigators will be responsible for ensuring the quality of their data via in-flight or ground-based calibrations. All instruments except CO_2 have flown autonomously before, and have established calibration procedures. The GHATTEX CO_2 instrument design and calibration procedures will follow that of a NOAA/AL instrument which has flown autonomously on the NOAA WP-3D aircraft. Instrument PIs will be responsible for submitting flight data to the archive after a careful evaluation for quality factors specific to their instrument.

3.6.3 Data Protocol *IP-Section 2.8.3*

All GHATTEX Project Team members subscribe to the following eight points of the data-sharing agreement as implemented in previous high-altitude airborne projects:

1) Preliminary data in graphical form should be available to all Science Team members within 24 hours after a flight.
2) Data that have undergone quality assurance checking by the respective Instrument PIs should be submitted to a common archive available to all Science Team members within 30 days after a flight.
3) Final data will be due 6 months after completion of the final GHATTEX flight. Submission of test flight data, although encouraged, will be up to the instrument investigators' discretion.
4) One year after the final flight, data will be made publicly available. This will be within 6 months after the formal end of the GHATTEX Project.
5) Each investigator's data are considered proprietary until the data are published in the refereed literature, or are published and released via the GHATTEX archives to the science community.
6) Individual GHATTEX members may release their proprietary data to whomever they wish. They may not release data of other GHATTEX members without consent.
7) An investigator whose proprietary data are to be used in an investigation has the right to be included among the authors of any resulting publication, but must work with the authors to determine such need.
8) GHATTEX members publishing results must always provide appropriate acknowledgement and citation of those who collected and provided the data, regardless of contribution to the publication.

3.6.4 Archival Plan *IP-Section 2.8.4*

A common password protected ftp archive will be established at the NOAA Aeronomy Laboratory. Data files following the NASA/Ames file format used for previous NASA ER-2 aircraft experiments will be submitted to that archive.

One year after the final GHATTEX flight (within 6 months after project completion), the archive will be moved to an anonymous ftp site on a NOAA/AL computer. The archive will also be made available to any requesting NASA data center and a CD-ROM produced. NOAA/AL has already hosted a password-protected data archive for two NASA WB-57F aircraft experiments, so no software development is required. Software currently in place automatically checks the files for format errors upon submission, and notifies the file creator as to any problems with the file. One computer to handle the GHATTEX data will need to be acquired prior to the first GHATTEX flights. S. J. Hovde and K. H. Rosenlof will be responsible for establishing and maintaining the data archive.

3.6.5 Roles and Responsibilities *IP-Section 2.8.5*

Instrument investigators will be responsible for checking the quality of their data and submitting data to the project archive in a timely manner as detailed in the GHATTEX data protocol given in **Section 3.6.3**. Instrument investigators will work on data analysis activities both independently and in conjunction with theory members of the GHATTEX Science Team. Specific analysis investigations and responsible Science Team members are listed in **Section 3.6.1**. Additional analysis will be the responsibility of the individual investigators. Data archive maintenance and CD-ROM preparation will be the responsibility of NOAA/AL.

4.0 Technical Plan IP-Section 3.0

4.1 Payload Integration Plan IP-Section 2.3

The approach to payload integration is conservative and driven by USAF constraints, by schedule and by cost. The primary consideration was to reach a payload installation design that would satisfy the scientific requirement for instrument inlet access to aerodynamically clean air (representative of the atmosphere), and also the USAF requirement that modifications to the airframe be minimal and rapidly (hours to one day) reversible. In addition, existing Global Hawk payload electrical and signal interfaces must be used.

The integration concept for the GHATTEX payload is for it to take the place of the SAR antenna and radome underneath the aircraft just below the wing attach points. The existing SAR radome will be replaced by a custom-built fiberglass fairing structure (FFS) with a similar aerodynamic envelope as the current SAR radome, but with the instrument air intakes and exhaust included. The instruments will be bolted to the easily attachable and detachable Airborne Payload Mounting Plate (APMP), and covered by the FFS. The location of the instruments within the FFS will be aided by the large payload volume margin. The enclosures of the new and existing payload components will mount in the payload area without interference from other payload components.

The Global Hawk's Integrated Mission Management Computer (IMMC) will control the GHATTEX AC and DC payload power using the same two output discrete commands now used to control the sensor payload power, and will use its avionics MIL-STD-1553 bus to communicate with the GPCC. The GPCC will be tested with a simulator during the integration preparation process.

Payload integration begins upon delivery of the instruments to the NOAA Aeronomy Laboratory with the electrical signal checkout of the interconnect cable between the GPCC and each of the instruments. This is followed by integration of the instrument control software running in the GPCC, and the verification that it functions as expected. In parallel, the mechanical design work required to mount the instruments on the APMP is completed, so that upon delivery of the bare APMP plate from NG-RAC, the instruments can be mounted on it and fit checked with all of the other instruments. Lastly, a final checkout of the APMP is completed at the Aeronomy Lab prior to its delivery to the NG-RAC Global Hawk Systems Center.

Upon receipt of the APMP at the NG-RAC Global Hawk Systems Center, aircraft integration testing will be performed in order to verify that:

- the interface with the IMMC works as expected;
- the instrument status information is correct;
- the payload APMP is compatible with the aircraft's electrical system; and
- there are no issues that would affect the safety of flight.

Upon completion of the final safety-of-flight checks in the Global Hawk Systems Center, the APMP will be delivered to the Birk Flight Test Facility located at EAFB Southbase where the Global Hawk UAVs are located. Once the APMP is delivered to Birk, the mechanical installation of the mounting adapters, electrical signal cables and the APMP is completed. After completion of the mechanical installation work on the UAV, the GHATTEX payload will undergo a series of tests including:

- an EMI compatibility check;
- a systems functional check;
- an engine run check;
- a pre-flight check run-through; and
- several taxi tests.

Once all of the aircraft integration work is completed, a flight readiness review (FRR) is held to show that sufficient testing has been successfully completed prior to first flight, and that the aircraft along with the payload is ready to perform its mission. The FRR will be conducted by the Global Hawk Chief Engineer's Office, WPAFB.

Once payload integration has been physically achieved and approval for flight has been obtained, there is provision for 24 hours of test flight(s) within the EAFB R-2508 flight test complex (see **IP-Figure 2.3-1** for a map of the R-2508 restricted airspace complex). The first flight will be a short one of 4 to 6 hours duration, and will primarily be used to verify that the instruments function as expected, that the in-flight operating procedures associated with the payload are checked out, and that the GHATTEX Project Team become familiar with the standard Global Hawk flight test routine. The last of these local test flights will be planned to include long flight segments near the high tropopause in order to expose instruments to low temperatures.

4.1.1 Payload Characteristics and Margins *IP-Section 2.3.1*

The GHATTEX payload instruments are specified in **IP-Table 2.1-2**, and their operational history in terms of research flights and hours by aircraft platform are shown in **IP-Table 2.3-1**. The total GHATTEX mass and power budgets, together with the capacity remaining on the Global Hawk, are shown in **IP-Table**

2.3-2. The payload volume occupies less than 50% of that available in the SAR payload area (see **Figure 3.2-2**).

Since the instruments were designed for and have operated in unpressurized, unheated space at up to FL680 at temperatures as low as -89ºC on the ER-2 and WB-57F aircraft, adequate environmental controls are already in place, as an integral part of each instrument. The operational histories for the ER-2 and WB-57F instruments were obtained under certification by the NASA authorities at Ames Research Center, Dryden Flight Research Center and Johnson Space Center. The CO_2 instrument was certified by NOAA for flight on the WP-3D at the agency's Air Operations Center, MacDill AFB, FL, and the new CO_2 instrument will be qualified through similarity and test.

4.1.2 Payload Integration Issues and Concerns *IP-Section 2.3.2*

As can be seen from **IP-Table 2.3-2**, there are generous margins for aircraft power and weight capacity. Therefore, the aircraft's performance and its ability to support the GHATTEX requirements are a low risk. This assessment will be further examined after the planned USAF flights of the Global Hawk to the equator and back, and to Australia and back prior to the performance of the GHATTEX mission flights. The payload installation was designed to be simple, and to use the existing aircraft infrastructure that currently supports the surveillance payload. There are no concerns in regard to the ability to rapidly convert the aircraft back to its surveillance configuration due to the modularity of the GHATTEX payload, and the fact that the aircraft modifications specific to GHATTEX are minor and do not interfere with the normal operation of the aircraft.

There are two areas to which the payload team will pay particular attention as GHATTEX unfolds. One is the payload integration; but the concern here is no greater or less than when the integration is on to a manned platform being used for the first time. An example is the WAM and ACCENT integration on the WB-57F of several instruments designed for the ER-2. The engineering team from NG-RAC and from the NOAA Aeronomy Laboratory (T. L. Thompson, R. H. Winkler) and the Instrument PI teams have long experience in the electrical, electronic and mechanical installation of sophisticated instruments on to high altitude aircraft.

A second area to which extra attention will be paid is in the implications of 25 and 32 hour flights for the instruments. All the instruments have successfully completed typical ER-2 and WB-57F flights of 8 and 6+ hours respectively, with the water, ozone, and MTP instruments having completed a 10.3-hour flight from Stavanger (59ºN, 6ºE) to Wallops Island (38ºN, 75ºW). All have been exposed for at least 6 hours at temperatures colder than -77ºC in unpressurized and unheated spaces, and have been run continuously in the laboratory for periods of days. As part of the instrument payload evaluation at the NOAA/AL in the integration phase, the payload instrument suite will be run for periods in excess of 32 hours, the planned duration of mission flights. Test flights will operate the instruments for extended periods and expose the payload to low temperatures. None of the instruments use cryogens, so payload preparation times and flight duration will not be constrained by cryogen hold times. The instrumental data are not being telemetered to the ground in real time, because of the cost to modify the UAV communications system for that purpose and because Ku SATCOM coverage is not available in the regions that GHATTEX will be flying in. However, the "health of the instruments" will be available in real time, and a rotation of scientists will be provided for consultation with the CCO in real time during each flight, particularly as regards the application of go/no-go criteria.

4.1.3 Instrument Modifications and Payload Integration Planning *IP-Section 2.3.3*

For the GHATTEX science payload, a suite of seasoned instruments was chosen that have a demonstrated successful flight history on the NASA ER-2 and WB-57F aircraft. In addition several of the instruments were also deployed on other platforms. Only two items will be new in the suite: a newly constructed CO_2 instrument and the GHATTEX payload control computer (GPCC). The CO_2 instrument is based on a commercial instrument. Two prototypes have already been extensively operated (> 200 hrs) by the Aeronomy Lab on the NOAA WP-3D and the NSF/NCAR Electra aircraft while conducting air quality research. On other platforms like the ER-2 and WB-57F, either the pilot or the scientific observer have command over the operation of the scientific payload via on/off switches. On the Global Hawk, the GPCC will take over this function. It will control the power distribution to the science payload and communicate with the separate instruments to monitor their health. The GPCC will use an off the shelf processor (PC104) and will be designed with the knowledge gained from the development of NOAA/AL computer-controlled instruments. These well-seasoned instruments are operated by Instrument PIs who are well-versed in adapting their instruments on to various platforms.

The integration process for the individual instruments can be broken down into three major task groups: mechanical, electrical and communications integration. All the instruments need to be mounted on the APMP, all need sampling inlets (except MTP and MASP), and some also need exhaust ports. The GPCC will provide power and communication connections to all instruments. Software needs to be written and tested that allows the individual instruments to communicate their health to the GPCC. Discussions with NG-RAC about the integration and all the pertinent issues are well underway. The specific modifications to individual payload instruments are documented in **IP-Sections 2.3.3.2** through **2.3.3.8**. Onboard communications and interface control document (ICD) development are described in **IP-Sections 2.3.4** and **2.3.5**, respectively.

The choice of the platform will make the mechanical and electrical integration straightforward and consequently low risk. All instruments aside from the MASP - which will be mounted to the wing structure - will be located in the SAR bay. Individual instruments are contained in one or more metal boxes that will be mounted to a common structure, the APMP. This concept allows integration and subsequent testing of the science payload separately before it is installed on the airframe. The mechanical integration will entail the design and fabrication of clips and brackets that tie the various boxes to the APMP. The design will be done in contact with NG-RAC which in turn is responsible for certification of structural integrity. The inlets and exhaust will be integrated and mounted to a new fairing (FFS) that NG-RAC will provide. The MTP instrument uses a microwave transparent window. This window will be integrated into a sub-fairing which then mounts to the FFS.

For the electrical integration we will tap into the science power bus in the SAR bay. The power distribution to the individual instruments will be controlled via individual sets of GPCC activated relays. Separate power harnesses for each instrument will be manufactured.

Communication between GPCC and the each instrument’s internal computer will proceed via RS-232 communication protocol. The communication protocol will be developed in close contact with the Instrument PIs by Mr. T. L. Thompson of NOAA/AL who will build the GPCC. Since there is only limited bandwidth available on the standard communication and control links from the mission control center to the Global Hawk, only limited data regarding instrument status and observations will be sent to the operations center.

The communication between GPCC and the Global Hawk control and communications components is accomplished via a MIL-STD-1553 interface. NG-RAC will define the communication protocol with the GPCC.

The payload integration will take place in several steps at several locations. It will start with the preparation of the instruments at their home institutions while NG-RAC designs and fabricates the APMP. After the APMP is delivered to NOAA/AL ten months after kickoff, the mechanical installation of the individual instruments and the GPCC will proceed. Also the power harnesses and communication harnesses from GPCC/power distribution to the separate instruments will be fabricated. Once this is accomplished, the operation of the science payload integrated on the APMP will be tested and verified (see **Figure 5.4-1**, Project Schedule**).**

The completed scientific payload will be shipped to NG-RAC 16 months after Program kick-off. At NG-RAC the payload and the power and communication interfaces will be tested on a simulator. After successful demonstration of performance and confirmation of no interference, the payload will be send to EAFB for integration on the airframe.

4.1.4 Payload Certification and Test Flights *IP-Section 2.3.6*

The majority of the instruments that comprise the GHATTEX payload have already been certified for flight in the expected UAV environment, and will require no further instrument level certification testing. The two subsystems requiring additional testing are the GPCC and the CO_2 instrument. These two subsystems will undergo a series of environmental tests in order to ensure that they will function in the expected environments. These environmental tests will include at a minimum, a vibration test per MIL-STD-810 using the defined UAV vibration levels (4.12 g rms for a minimum of 15 minutes in each of the three axes), and a temperature–altitude test per MIL-STD-810 in which the subsystems will be subjected to the equivalent altitude and temperature environment expected at 65,000 ft.

Certification of the payload for flight on the Global Hawk entails more than verifying that the instruments will operate properly in the expected environments. Certification also requires a sufficient level of system level testing to verify the function of the flight-critical systems necessary to accomplish mission objectives. (The expected verification testing has already been defined above in the introduction to **Section 4.1**) The culmination of this testing results in a FRR, where the Chief Engineer of the Global Hawk Special Program Office has an opportunity along with his staff and support organizations to examine the test data. The result of the FRR is then the approval for flight of the GHATTEX mission.

After the FRR, one additional test will be performed, the "takeoff-abort" test. This test is usually performed a few days prior to the first flight after a major change in the aircraft configuration, and requires the entire mission crew, including the GHATTEX support personnel, to go through the mission launch procedures just as if the aircraft was going to fly. The aircraft is prepared for flight and towed out to the mission start waypoint, powered up normally, commanded to taxi to the runway, and then commanded to takeoff. The rotation speed (V_R) during pre-flight is set very low, so that the aircraft will automatically abort the takeoff.

A few days later, the first test flight of the GHATTEX mission will be flown entirely within the R-2508 restricted range complex. As stated above, the first test flight will be a short one of 4 to 6 hours duration, and will primarily be used to verify that the instruments function as expected, that the in-flight operating procedures associated with the payload are checked out, and that the GHATTEX Project Team is familiar with the standard Global Hawk flight test routine. There is provision in our proposed budget for a total of 24 hours of "test" flights, and for planning purposes we expect to need only one additional test flight in which the aircraft will fly a 16- to 20-hour mission. This second test flight will include long flight segments near the high tropopause in order to expose instruments to low temperatures.

The performance of the interface between the aircraft and the payload during test flights will be monitored by NG-RAC and NOAA/AL engineers. The performance of the instruments will be monitored, and selected housekeeping and science data recorded by the GPCC **(IP-Section 2.3.4)**, in addition to the storage of such data which is built into each instrument. The long performance heritage of the instruments will serve as a benchmark against which fully satisfactory performance during the test flights can be established. The Project PI, in close consultation with the Instrument PIs, will decide when the payload is science ready (see Science Readiness Review, Project Schedule, **Figure 5.4-1)**.

4.2 Deployment Plan IP-Section 2.4

The deployment plan will consist of a test flight period of 4 weeks and 2 mission deployments of 3 weeks each during which the instrument teams and the science team deploy to EAFB. The test flights and mission deployments each include a one-week contingency period to allow flexibility in meeting objectives. All flights will launch and recover from EAFB. The test flight period will begin 16 months after receipt of funding, and use the 24 hours budgeted for test flights. The first mission deployment in winter 2002/2003 will include one 'meridional' transect flight and one 'triangular' Pacific Basin flight (see **Section 4.3**). The second mission deployment will include the same pair of flights in the period July – September 2003. This pattern of flights will meet the requirements for long surveys of the tropical Pacific, both well into the Southern Hemisphere, and of the equator to Australia, in the seasons that offer maximal contrast in the temperatures near the tropical tropopause. The GHATTEX Project Schedule has large flight windows for each of the summer and winter flights and a backup winter flight window to provide substantial flexibility in achieving the planned number of flights. The Project Schedule is shown in **Figure 5.4-1**.

4.2.1 Deployment Concept IP-Section 2.4.1

The Birk Facility at EAFB will provide the space used during deployments. With the exception of the MTP instrument, the payload instruments and their support equipment will be shipped from Colorado three days before the beginning of each three-week deployment. The MTP instrument will travel from JPL (Pasadena) to EAFB by a method selected by the instrument PI. The shipment from Colorado will be made with a single air-conditioned, air-ride moving van. This shipping method has proven successful in previous deployment activities involving the NASA ER-2 and WB-57F aircraft. Other shipments of instruments and support equipment to NOAA/AL, to the NG-RAC facilities in California, and to the Birk Facility will be handled separately by individual investigators as needed.

The laboratory space will be in the Birk Facility in close proximity to the Global Hawk hangar space. The payload will be bolted to the APMP at the NG-RAC Global Hawk Systems Center, delivered to the Birk Facility, and electrically connected to the IMMC via the GPCC. It will then be tested for electrical, mechanical and scientific functionality with the FFS attached in place with the air inlets embedded.

The next stage will be to perform taxi tests with the payload and its fairing in place, according to the procedures established by NG-RAC/USAF for Global Hawk operations. Two such trials are planned. Following successful completion of taxi trials, the first test flight will be under taken. If the instruments function normally, as revealed by the “health of the instruments” data stream, the flight will be continued to six hours duration and the Global Hawk recovered. The instrument teams will then analyze the scientific data for quality and completeness. Instrument adjustments will be undertaken as needed based on the data analysis. Further test flights will be scheduled as deemed necessary by the Instrument-PI group and aircraft operations personnel until test flight requirements are satisfied. After instruments are performing satisfactorily, the time remaining in the total of 24 test-flight hours will be used in a last test flight to expose the payload to low ambient temperatures near the subtropical tropopause over EAFB. After the test flights, the first mission deployment will include the two winter flights, starting with the 25-hour Meridional TransEquatorial flight ((34ºN, 118ºW) → (35ºS, 111ºW) → (34ºN, 118ºW)). After this flight, the 32-hour Triangular TransPacific flight will be undertaken (see **Section 4.3**). During the next six months, the data will be analyzed so as to provide maximum feedback and insight for the repeat of the flight pair during the following summer. After the summer pair of flights, the remaining months will be used for scientific data analysis.

4.2.2 Facility Needs — *IP-Section 2.4.2*

The needs for the deployment of the GHATTEX payload and Science Team to EAFB are as follows:

- Space for the payload and Science Team at the Birk Facility where the Global Hawk is based.
- Minimum 1500 sq. ft. of space, enclosed by walls and roof, air conditioned, with clean, sealed floor.
- 27 standard tables, approximately 60" L x 36" W x 30" H with one chair for each table.
- Access door to permit entry of ground carts up to 48" width.
- The following power supplies must be readily distributable among the tables:
  - 60A, 60Hz, 115 VAC; 7kVA, 400Hz, 115 VAC; 3kW, 28 V DC
- Two computer drops, easily connectable to hubs
  - NOAA/AL will supply each 16-port hub connectable to the table locations.
- 32 addresses for connectivity to the Internet via the hubs.
- Access to GHATTEX home institutions through any firewall is required.
- Access for GHATTEX Project Team to the facility through any security checks that apply. There are 7 non-U.S. citizens involved, 3 Canadians, 1 German, 2 Britons, and 1 New Zealander. Of these, 2 Canadians and 1 German are part of the Instrument PI teams for whom access to the Global Hawk in the Birk Facility is essential. All non-U.S. citizens are permanent residents or possess a work visa.

The hangar, range, communications and support needs are to be supplied by USAF through EAFB, and are in regular use by the Global Hawk. Facilities costs have been provided by EAFB and are included in the GHATTEX budget (see also commitment letter from EAFB in **Appendix C**). Deployment activities will be scheduled when support can be provided by 452nd Flight Test Squadron (FLTS) at EAFB.

4.2.3 Expendables — *IP-Section 2.4.3*

Expendables will be carried on board the aircraft by three instruments and used on the ground during deployments. The materials all have established handling procedures and do not pose a hazard to personnel. No cryogens are used on board the aircraft. Further details are provided in **IP-Section 2.4.3**.

4.2.4 Scope — *IP-Section 2.4.4*

The plan is for three deployments to EAFB:

(1)	Test flights	September 2002	3 wks plus 1 wk contingency	
(2)	Winter flights	November 2002 - March 2003	2 wks plus 1 wk contingency	2 science flights
(3)	Summer flights	July - September 2003	2 wks plus 1 wk contingency	2 science flights

Each deployment period includes a one-week contingency to extend the deployment if instrument, platform, weather, or other difficulties arise. The planned order of flights within the winter and summer deployments is the Meridional TransEquatorial flight followed by the Triangular TransPacific flight (see **Section 4.3**).

4.2.5 Deployment Readiness Review *IP-Section 2.4.5*

A Deployment Readiness Review (DRR) will be held at monthly intervals during GHATTEX using email inquiries to the Science Team, with issues structured according to the WBS (**Figure 5.2-1**) and Project Schedule (**Figure 5.4-1**). In this way, every activity important for the deployments will be under periodic review.

Reviews will be held as teleconferences conducted by the GHATTEX Project PIs from Boulder during which all activities critical to success will be reviewed. Dr. Tuck and Dr. Fahey will be responsible for determining review objectives and conducting the review. Deployments will be scheduled only after a successful Flight Readiness Review **(Section 4.1.4)** that will address payload integration status. When the payload is deemed ‘flight ready,’ the Test Flight Readiness Review will be conducted to address issues and scheduling of the Test Flight Deployment **(Section 4.1.4)**. Two further DRRs will precede the Winter and Summer Deployments, respectively. The Science Readiness Review will signal the successful completion of the test flight phase. The timing of these reviews is available in the Project Schedule **(Figure 5.4-1)**.

4.2.6 Schedule *IP-Section 2.4.6*

The GHATTEX Project Schedule is specified in **Figure 5.4-1**. Test flights are planned in September 2002, followed by winter flights in the period November 2002 to March 2003 and summer flights in the period July to September 2003. The project flight windows provide flexibility to schedule the three-week deployment period and with consideration of other USAF commitments of Global Hawk personnel and resources.

4.2.7 Roles and Responsibilities *IP-Section 2.4.7*

We view it as essential to have key roles performed by individuals who are not only fully qualified, but who have shared participation in GHATTEX from its inception. **IP-Table 2.4-1** lists the roles and responsibilities of the principal participants of GHATTEX. In several cases, more than one name is listed against the role. In each case, the responsibility is that of managing the execution of the duties associated with the role, which will often involve a sub-team of others.

4.3 Flight Plan IP-Section 2.5

This section will define the GHATTEX project flight concept, and all of the relevant parameters associated with planning and actually carrying out the proposed flights. Mission planning will be performed by NG-RAC, with input from the Project PIs and the Project Coordinator, using the standard mission planning procedures already established for the operation of the Global Hawk UAV. The actual mission plan is generated using an Air Force Standard mission-planning tool known as AFMSS (Air Force Mission Support System) that has been adapted for use on Global Hawk. In addition, there are several documents that have been used in the Global Hawk mission planning process and will be used in GHATTEX. These documents include “AFFTC Instruction 11-1, Edwards AFB Range Procedures” (**IP-Appendix H**), and NG-RAC Document Number 367-5000-891, “Global Hawk Mission Planning Guide.” The mission flight concept and flow are described in **IP-Section 2.1.1** and **IP-Figure 2.1-1**.

4.3.1 Mission Flight Concept *IP-Section 2.5.1*

GHATTEX proposes two pairs of flights, one pair occurring during northern winter, and one pair of flights during northern summer. Each pair of flights consists of a Meridional TransEquatorial flight in the Eastern Pacific region, and a Triangular TransPacific flight in the Central Pacific region (see **Figure 4.3-1**).

The Meridional TransEquatorial flight will originate out of EAFB located in California’s Mojave Desert, and stay within the R-2508 restricted airspace complex (**IP-Figure 2.3-1**) until the aircraft is above FL450 (45,000 ft). The aircraft will then proceed along its programmed route over sparsely populated areas to the coast, fly south-southeast along the coast in international airspace to intercept the 111° meridian, proceed due south along the 111° meridian to 35° south latitude in international airspace, then return along the same route. The outbound leg will be flown using the aircraft’s normal cruise climb mode at an altitude no higher than FL650, and thus will be in the lower stratosphere. During the return leg, the aircraft will be

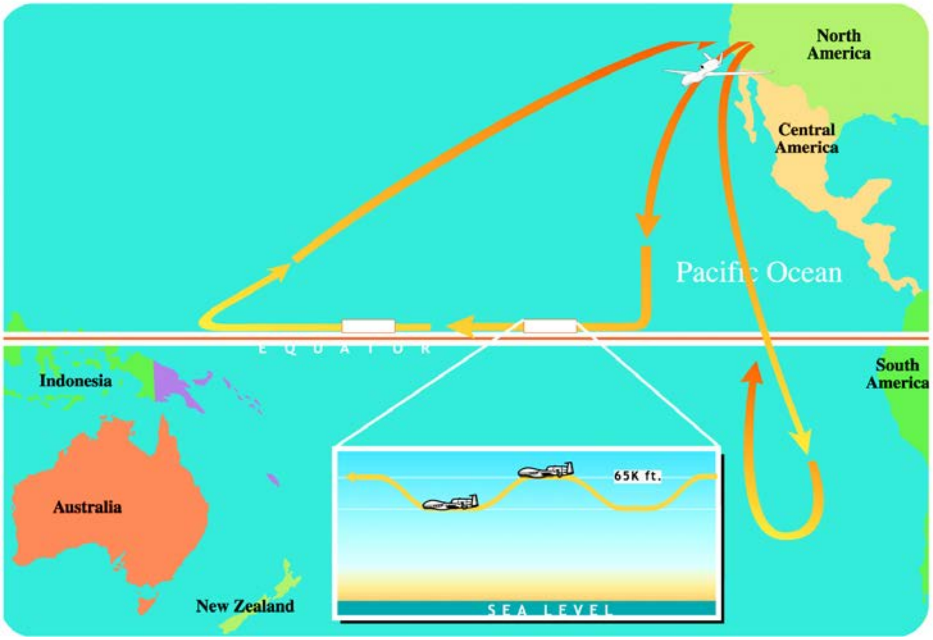

Figure 4.3-1 Schematic of proposed flight plans for the Global Hawk UAV. The two mission flights in each science deployment will be the Meridional, TransEquatorial flight followed by the triangular, TransPacific flight. Both flights will take off and land at EAFB, CA.

commanded to descend to and fly at three discrete altitudes for sampling purposes. These three discrete altitudes are currently planned to be FL450, FL500 and FL550. After the discrete altitude sampling is completed, the aircraft will be commanded to climb back to nominal cruise altitude taking samples along the route back to EAFB.

The Triangular TransPacific flight will also originate out of EAFB, and will again stay within the R-2508 restricted airspace complex until the aircraft is above FL450. The aircraft will then proceed along its programmed route over sparsely populated areas to the coast, proceed south along a great circle route to (7°N, 135°W) in international airspace. Once the aircraft reaches 7°N latitude, the aircraft will proceed along the 7°N parallel until reaching approximately 155°E longitude. At (7°N, 155°E), the aircraft will fly a great circle route back to EAFB. During the portion of flight along the equator, the aircraft will be commanded to descend down to FL450 several times in order to take samples at these lower altitudes.

4.3.2 Flight Planning Criteria *IP-Section 2.5.2*

Each mission flight will have specific flight plan criteria. During the test flights, aircraft systems and the instrument payload will be the dominant considerations (see **Section 4.3.3)**. Flights will be planned to demonstrate the performance of each with flights of increasing length. Flight tracks will remain over the EAFB range where air space management issues are routine for the Global Hawk Test Team (see **Section 4.5**). For the mission flights, scientific flight planning criteria will be added in addition to the aircraft and instrument criteria.

4.3.2.1 Scientific flight planning criteria *IP-Section 2.5.2.1*

Meteorological flight planning tools for high altitude aircraft have been developed at the NOAA/AL. These computer programs have been used most recently during the WAM (1998) and ACCENT (1999) missions with the WB-57F aircraft. Input data to the programs consist of NCEP aviation forecasts and NOAA satellite images. Wind, temperature, estimates of cloud top temperature and other derived fields such as potential vorticity were used to plan flight tracks through scientifically interesting regions that were also deemed safe by the WB-57F pilots. Forecast files were downloaded as soon as they become available from the NOAA Information Center and satellite data was obtained from both Unidata and NASA data feeds. For this experiment, safe operation of the UAV around regions of convection is of great concern.

Because of this, more timely satellite information than available through standard Unidata sources is required. During 2001, the USAF will fly the Global Hawk to Australia for an extended deployment. During that time the Global Hawk's operators will undoubtedly gain significant knowledge and experience in flying the aircraft in the vicinity of severe tropical convection. This added knowledge will be incorporated into our flight planning procedures. The required satellite information will be available through USAF channels. However, if needed, CIRA at the Colorado State University can provide GOES cloud top temperatures information on a contract basis. For coverage in the Far Western Pacific, data from GMS or polar orbiting satellites will be required. The U.S. Navy runs a receiving station that can obtain GMS data real time, and initial contacts indicate that they could provide the required information on a contract basis.

Statistically, the highest clouds in the tropical Pacific occur between 100ºE and 140ºE (based on OLR averages). For this reason, the first science flight will transect the equator in the eastern Pacific. This will only require GOES-W data, and avoid regions of statistically most active convection. The coldest cloud top temperatures within range of the planned flights occur in January and south of the equator. Therefore, a longitudinal transect at 7ºN in Northern Hemisphere winter will be quite possible. A mid-summer longitudinal transect will be possible, but will require careful monitoring of conditions via satellite. The location of the Pacific warm pool also impacts where severe convection is likely to occur, and pre-flight-day planning will also take that into account also using current information from satellite.

4.3.3 Go/Go-No Criteria *IP-Section 2.5.3*

The mission go/no-go criteria can be considered in two parts: the aircraft specific go/no-go criteria and the payload go/no-go criteria. The basic flight planning criteria for the aircraft include taking into account safety of flight issues, contingency and alternative landing fields, and programming in communications frequencies for the long over water flight. These issues are addressed in part in **IP-Appendices E** through **I** and have been taken into account in USAF extended mission flights of the Global Hawk to Alaska and Portugal. The specific aircraft go/no-go criteria include weather related criteria, aircraft system related criteria, and FAA/AFFTC specific criteria. **IP-Table 2.5-1** is a summary of the aircraft specific go/no-go criteria. Implicit in the payload criteria evaluation is that the GPCC must be fully operational.

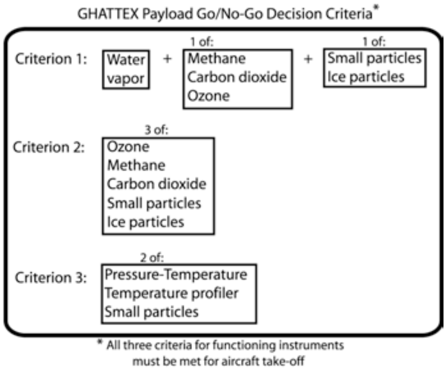

Figure 4.3-2 Go/no-go criteria for Global Hawk UAV payload on mission flights.

The payload specific go/no-go criteria are illustrated in **Figure 4.3-2**. As can be seen from the figure there are three go/no-go criteria associated with the payload, and these can be summarized as follows:

- The water instrument must be functioning and must be accompanied by a measurement instrument which can be used as a tracer near the tropical tropopause, and by some information about the behavior of the particulate matter;
- There must be either two particle measurements or two tracer measurements to accompany at least one in the other category;
- There must be adequate information available post-flight about the prevailing meteorological conditions.

4.3.4 Roles and Responsibilities *IP-Section 2.5.4*

The USAF 452nd Flight Test Squadron (FLTS) has responsibility for Global Hawk UAV operations at EAFB. The Project PI has responsibility for making the flight plan request, which embodies the Science Team's requirements, to the 452nd FLTS. The flight planning procedure used by the 452nd FLTS has been thoroughly developed and exercised over the 65 flights of the Global Hawk to date (see **IP-Appendix D** and **Sections 4.4** and **4.5**). The Instrument-PI teams have responsibility for preparing their instruments for flight at the deployment site, integrating them on board the aircraft before flight, participating in pre-flight tests and checks, and downloading their instrument after a flight.

4.4 Non-NASA Aircraft Safety Plan IP-Section 2.6

The Global Hawk UAV is a non-NASA aircraft owned by the U.S. Air Force and operated at EAFB. Flight test safety at EAFB (also known as the Air Force Flight Test Center or AFFTC) is governed by a number of U.S. Air Force instructions and guidelines. These guidelines and instructions were followed during the initial developmental flight testing of the Global Hawk UAV, as well as during its operational utility assessment flights. These guidelines will continue to be utilized and followed for GHATTEX, and form the basis for our compliance with NASA's aircraft safety policy. These documents include the following and are provided as addenda to the Implementation Plan (**Appendix I**):

- **IP-Appendix E: Flight Safety and Technical Considerations Guide for Flight Testing, AFMC Pamphlet 91-1, 18 March 1997.** This appendix, written by the Air Force Materiel Command as a guide for U.S. Air Force sponsored flight tests, established the framework in which the Global Hawk flight test process was developed. It essentially provides a "checklist" for what questions need to be raised when performing and conducting flight tests out of the EAFB Flight Test Center, with the specific goal of leading flight test participants to consider all the risk factors that may be encountered during the flight test process.
- **IP-Appendix F: AFFTC Test Safety Review Process, AFFTC Instruction 91-5, 12 July 1999.** This appendix, written by the U.S. Air Force Flight Test Center staff contains specific instructions on how to reduce the risk of mishaps during flight test activities. This instruction pamphlet has been utilized throughout the Global Hawk UAV flight test program as the basis for the preparation and presentation of safety related data to the applicable safety review boards.
- **IP-Appendix G: Range Safety Criteria for Unmanned Air Vehicles, RCC Document No. 323-99, December 1999.** (http://afmc.wpafb.af.mil). This appendix, written by the Range Commanders Council's Range Safety Group, provides guidance on how to answer the question: "Is this unmanned air vehicle safe to fly on my range?" This document was also utilized during the Global Hawk flight test program to further ensure flight safety.
- **IP-Appendix H: Remotely Operated Aircraft Tests (ROA), R-2515, AFFTC Instruction 11-1, Attachment 1, April 1998.** This instruction pamphlet provides specific procedures for the conduct of flight tests of unmanned air vehicles, and is followed for all flights of the Global Hawk. The worksheet at the end of this document is filled out for each Global Hawk flight in order to obtain the appropriate approvals for that particular flight.
- **IP-Appendix I: Preliminary Safety Analysis for the Tier II+ HAE UAV, TRA Report No. 367-4100-159.** This safety analysis was prepared by the NG-RAC system engineering staff prior to the Global Hawk's first flight in order to systematically identify and provide mitigation plans for the specific hazards associated with flight of the UAV. It is important to note that this systematic review of the applicable safety hazards of the aircraft identified no unacceptable system safety hazards. This review is provided here in order to further satisfy NASA's safety policy, and substantiate our assertion that the Global Hawk UAV is safe to fly.

The flight safety review and decision process described in these appendices is currently used by the USAF and NG-RAC in Global Hawk operations and will satisfy NASA requirements for the operation of non-NASA, Department of Defense-owned, aircraft in NASA funded projects. This conclusion was reached in teleconference discussion with Mr. Warren Hall of NASA Ames Research Center in November 2000 who is a NASA-designated safety representative for aircraft operations. GHATTEX reviews are included in the Project Schedule (**Figure 5.4-1**) and listed in **IP-Section 3.2.1**.

The flight testing and safety analysis already carried out for the Global Hawk UAV is the basis of aircraft safety and mission assurance for GHATTEX and the assertion that the Global Hawk UAV is 'safe to fly.' GHATTEX mission flight parameters are within or comparable to those demonstrated to date (see **Sections 3.1-3.3**) and show that the Global Hawk has the capability to meet the flight requirements. The 65 flights of the Global Hawk demonstrate its airworthiness (**IP-Appendix D**). The background and experience of the operators, as developed over the course of the Global Hawk program within the USAF, are adequate to operate the Global Hawk in GHATTEX. The requirements of GHATTEX will not expose the service provider, the USAF, or the manufacturer, NG-RAC, to risks beyond their capabilities. The GHATTEX payload is a suite of customized sampling instruments developed for airborne platforms and, hence, is unique and of high value. The value of the payload and the aircraft warrant operation under strict safety rules.

Also, in compliance with NASA's aircraft safety policy, the Memorandum of Agreement (MOA) executed between NOAA and the U.S. Air Force includes a definition of the roles and responsibilities for conducting flight operations for GHATTEX (see the draft MOA in **IP-Appendix J**). The Air Force will specify that their contractor, NG-RAC, be responsible for conducting the actual flights, with operational oversight by the responsible test organization located at AFFTC. All flights conducted for GHATTEX will continue to follow the standard procedures already established for conducting Global Hawk flights. Also included in our project plan is a formal flight readiness review in which readiness and safety will be assessed prior to the first flight of GHATTEX in accordance with Global Hawk standard operating procedure.

4.4.1 Flight Test Safety of the Global Hawk ____ *IP-Section 2.6.1*

The process used to approve the Global Hawk UAV for its maiden flight at EAFB began with the preparation, by the Global Hawk development contractor, of the 'Preliminary Safety Analysis for the Tier II+ HAE UAV' (**IP-Appendix I**). This analysis systematically identified safety critical hardware and software areas, provided an assessment of hazards, and documented requisite hazard controls and follow-on actions. The Global Hawk UAV was specifically evaluated for hazard severity, hazard probability, and operational constraints based on the best available data, including mishap data from similar systems and other lessons learned. Safety provisions and alternatives needed to eliminate hazards or reduce their associated risk to an acceptable level were also included in the analysis. A preliminary assessment made for this Implementation Plan identified no hazards unique to GHATTEX that have not already been identified in either **IP-Appendix I** or in the numerous safety review boards held during the flight testing of the Global Hawk UAV.

The Preliminary Safety Assessment (**IP-Appendix I**) was used as source material for preparation of a series of "Safety Review Board (SRB)" briefings as required by the documents cited above. It was the approval of the SRB package that authorized the Global Hawk flight test team to proceed onto the next series of tests in the flight test program. At each major juncture in the test program, an SRB was convened to review the test plans for the upcoming series of tests and any safety risks associated with those tests.

In preparation for an SRB, a detailed flight test plan document was generated that defined test objectives, outlined tests to be performed, addressed special procedures to be followed, and delineated safety and security requirements. In addition, "Test Hazard Analysis" (THA) sheets were also prepared. **IP-Table 2.6-1** provides a list of the SRBs and other applicable flight readiness reviews held. It illustrates that the process used to approve the aircraft for flight was very systematic. Based on the extensive and systematic flight-safety assessments already completed for the Global Hawk, it is judged fully acceptable to undertake GHATTEX flight objectives.

4.4.2 Weather Risk during Science Flights ____ *IP-Section 2.6.2*

The primary weather conditions that could be relevant for Global Hawk safety in the tropics are deep thunderstorms and temperatures below the -77°C to which the aircraft is certified. These conditions will be known and monitored in real time through the satellite link relaying the aircraft flight data back to the CCO at EAFB, and from the weather satellite data links available there from existing USAF sources, which will also be available from the GHATTEX flight planning suite. The real-time data from the Global Hawk can be used to take avoidance action if the temperature approaches the certification limit, and the satellite data can be used to plan avoidance action from deep thunderstorms. Thunderstorms above 50,000 ft over the continental U.S. in summer have been avoided by these means. By the time of GHATTEX, the USAF will have done flights in the tropical eastern Pacific and out of Australia, including the transit flights to and from EAFB that necessarily transect the region of the GHATTEX triangular TransPacific flights. These operations are underpinned by the considerations in **Sections 4.1** and **4.3.2**, **IP-Appendices E-I** and **K**.

4.5 Airspace Management Plan ____ IP-Section 2.7

The Global Hawk UAV will be operated only from EAFB during GHATTEX project flights. Global Hawk has been approved for operations over EAFB, in FAA-controlled air space, in international air space, and over the Pacific and Atlantic Oceans (see **Section 3.3**). Operations in all of these areas have been successful. Access to airspace in GHATTEX will follow procedures already established within the Global Hawk flight test program.

The GHATTEX mission flights in FAA-controlled airspace will be conducted in accordance with FAA Order 7610.4J, Chapter 12, Section 9, since the aircraft is a military owned and remotely operated aircraft (ROA). Order 7610.4J, Chapter 12, Section 9 requires that, for the operation of the Global Hawk:

- an FAA approved Certificate of Authorization (COA) be acquired;
- the aircraft be equipped with standard aircraft position lights and high intensity strobe lights in accordance with criteria stipulated in 14 CFR, Section 23.140;
- the aircraft be equipped with an altitude encoding transponder that meets the specifications of 14 CFR, Section 91.215;
- the aircraft lights be operated during all phases of flight;
- the transponder shall be set to operate on a code that is assigned by air traffic control, and that the ROA pilot-in-command have the capability to reset the transponder code while the ROA is airborne;
- the ROA shall be equipped with instantaneous two-way radio communication with all affected ATC facilities;
- the ROA pilot-in-command complies with all ATC clearances; and
- the proponent and/or its representatives, shall be noted as responsible at all times for collision avoidance maneuvers with nonparticipating aircraft and the safety of persons or property on the surface.

The aircraft is currently operated under the auspices of COAs issued by the manager of the Western Pacific Region Airspace Branch (see **IP-Appendix K** for an example of a Global Hawk COA). As shown in **IP-Table 2.7-1**, the aircraft is in full compliance with the requirements of Order 7610.4J, Chapter 12, Section 9, and will be flown in accordance with the provisions of the COA issued for the aircraft during the period of the GHATTEX flights. As a condition of the COA, specific requirements exist for coordination procedures, communications procedures, traffic avoidance procedures, and Lost Link/Mission Abort procedures. These are described in **IP-Section 2.7.1**.

4.5.1 International Air Space IP-Section 2.7.2

The conditions for operating in international air space have been fulfilled by the Global Hawk during its mission to Portugal, and will be fulfilled by USAF flights in a way relevant to both GHATTEX profiles when operating in the eastern Pacific and en route to Australia during 2001. If these missions involve overflight of small islands belonging to other nations, the USAF will handle obtaining overflight permission. The GHATTEX flights could be planned to detour around these nations, if necessary.

5.0 Management Plan IP-Section 3.0

The GHATTEX management structure shown in Figure 5.0-1 is based on existing relationships between the participants. The Project PI (Dr. A. F. Tuck) will have the primary responsibility for management of the GHATTEX. He will establish adequate information channels to continually monitor all and any part of the project, and instructional channels to implement project decisions. He will preside over an electronic (Internet) forum by means of which discussion of problems and decisions can be effected on a timely and continuing basis. Physical meetings will be held involving project staff as the need arises. Monthly and quarterly reviews of the project will be incorporated as milestones. The lines of communication will go from the Project PI to the following individuals: the Project Co-P.I. (Dr. D. W. Fahey), the Project Coordinator (Dr. G. Hübler), the USAF ASC/RAV representative (1st Lt A. Wehner) (a program manager is to be appointed by ASC/RAV upon award of funds by NASA), the NG-RAC representative (Mr. G. Loegering) (a program manager will be appointed by NG-RAC upon award of funds by NASA), and the Education and Public Outreach coordinator (Dr. S. Buhr). These individuals will have lines of communication into the five task areas (**Figure 5.0-1**), as necessary. The USAF and NG-RAC representatives and managers have responsibilities primarily within their own institutions, while the Project Coordinator will communicate with the Project PIs, the PIs of the Instrument and Theory Teams, and as necessary with USAF and NG-RAC.

The data and information tools by which the Project PI will monitor the project will be the Project Schedule **(Figure 5.4-1)**, the GHATTEX Work Breakdown Structure **(Figure 5.2-1)**, and the Risk

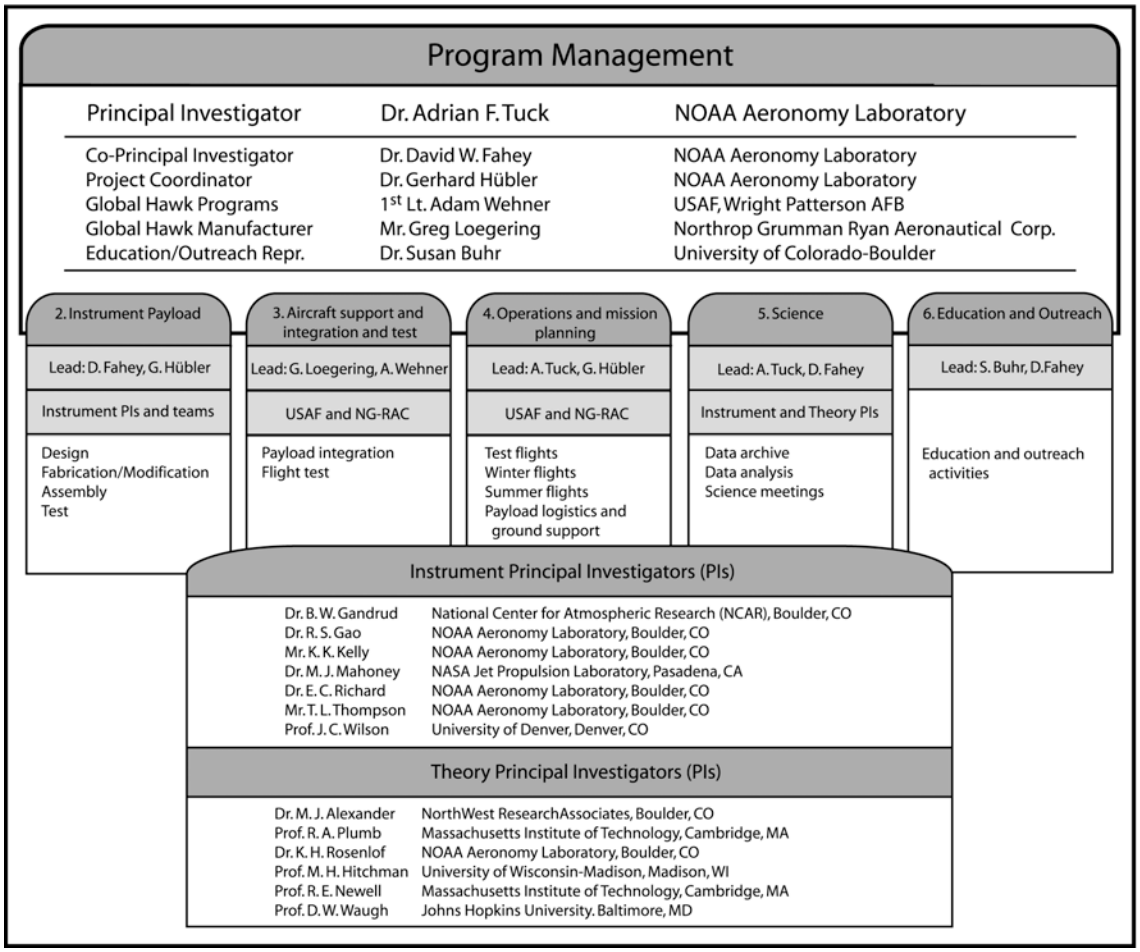

Figure 5.0-1 GHATTEX management structure

Assessment matrix **(IP-Table 3.6-3)** associated with the WBS. Each person identified as having cost and schedule responsibility will be tasked with providing a monthly status report to the Project Coordinator via email. Roles and responsibilities of project personnel are listed in **IP-Table 2.4-1**, GHATTEX Personnel Responsibilities. Management of tasks during the pre-deployment, deployment, and post-deployment phases are described in **IP-Sections 3.1.1, 3.1.2,** and **3.1.3**, respectively.

The primary managerial link from the PI institution (NOAA/AL) is to ASC/RAV, defined in an MOA between NOAA and USAF (**IP-Appendix J**). This arrangement allows GHATTEX to join smoothly to and leverage off the existing management structure for the Global Hawk UAV. This structure has evolved over more than five years and has been shaped by and incorporates system engineering approaches and project control tools. Upon award of funding by NASA, ASC/RAV and NG-RAC will appoint Program Managers for full-time support of the GHATTEX effort. This will facilitate both management of key GHATTEX tasks and avoid conflicts with the baseline USAF program with the Global Hawk.

The management approach for GHATTEX is Integrated Project Management (IPM) as depicted **Figure 5.0-1**. The GHATTEX Project PI has overall responsibility for GHATTEX. The Project PI is supported by the Project Co-PI, Project Coordinator, program representatives from the USAF and NG-RAC, and a Education and Public Outreach Coordinator. These key personnel provide lead the management of all Level 2 tasks of the WBS with direct communication to the Project PI. This management team provides guidance, instruction, and oversight to the larger group comprised of Instrument PIs and Theory PIs. Personnel within USAF and NG-RAC will be managed by their respective institutions. There is communication both vertically and horizontally within the IPM structure in **Figure 5.0-1**, as the project situation demands. Because the GHATTEX requirements were frozen at an early stage, which was in large part possible because of the maturity of the payload instruments and of the platform, the IPM and the WBS were defined in a clear manner early in the genesis of GHATTEX.

The Instrument PIs and the Theory PIs are central to the project; they have the responsibility for managing their individual activities, using the established internal procedures at their respective institutions. The Project Control Plan, described in **Section 5.3**, delineates how the IPM will work coherently in the overall GHATTEX project.

5.1 Roles and Responsibilities IP-Section 3.3

The GHATTEX Project Team and Personnel Responsibilities are listed in **Table 3.2-1** and **IP-Table 2.4-1**, respectively. Changes to personnel from the original proposal are: the addition of Prof. M. Hitchman, Prof. R. Newell, and Prof. D. Waugh as theory investigators; and the selection of Dr. G. Hübler as Project Coordinator. All Team members have qualifications and experience (**Appendix D**) that are highly relevant to their role in GHATTEX, as outlined in the attached curriculum vitae.

The Project PI has overall responsibility for GHATTEX. Specific duties include:

- cost and schedule performance;
- defining the science goals of GHATTEX;
- recommendations to change scope based on the science objectives and available resources in the event of operational difficulties;
- maintaining communication between all participants;
- preparing for and participating in design, safety, and flight readiness reviews;
- distributing funding resources to all participating institutions and monitoring contractual arrangements with non-government institutions;
- assigning the Project Coordinator with essential tasks related to the instruments, aircraft, and field activities;
- flight planning activities related to meeting the science objectives within operational constraints;
- arranging for and leading discussions of the interpretation of flight data; and
- preparing the Science Report from GHATTEX.

The dedicated GHATTEX Project Co-PI has significant advantages for mission planning, mission execution, and scientific data evaluation. The Project Co-PI will support the Project PI in all phases of the project. While the Project PI has overall responsibility for GHATTEX, the Project Co-PI will share responsibility for many aspects of the planning and execution, thereby making the management process more effective and efficient. Sharing responsibility will be particularly important during the deployment phase when many issues need attention and decisions must be made promptly. The Project PI and Co-PI will keep each other fully informed of matters as they evolve so that either could take a decision or action if circumstances dictate.

We note that the Project PI was the Project Scientist for the AAOE and AASE ER-2 and DC-8 missions, which pioneered the airborne investigation of polar ozone loss from the Straits of Magellan and Norway, in 1987 and 1989 respectively. He was also Project Scientist for the ASHOE/MAESA mission from New Zealand and Hawaii in 1994, and for the WB-57F Aerosol Mission (WAM) from Houston in 1998, which was a successful PI-mode project. The Project Co-PI was the Project Scientist for the POLARIS ER-2 mission from Alaska in 1997, and was the Instrument PI for the NO/NO_y instrument on nine ER-2 missions between 1987 and 2000, in addition to being Instrument PI for the new CIMS instrument for HNO_3 during the ACCENT mission in 1999. The Project Coordinator has fulfilled this role on the NOAA WP-3D missions that have used a comprehensive suite of chemical instruments to investigate air quality in the troposphere over the U.S. and the North Atlantic.

The Project Coordinator will work closely with the Project PI and Co-PI to coordinate all aspects of the project. The Project Coordinator will:

- monitor cost and schedule compliance;
- interface between the Science Team and the flight organization;
- handle communication among participants regarding instruments, payload configuration, data handling, and field deployments; and

- act as coordinator for the instrument groups during field deployments.

The GHATTEX management structure (IPM) is shown in **Figure 5.0-1**. The Project PIs, USAF, and NG-RAC will maintain close collaboration and communication regarding the preparation and use of Global Hawk in GHATTEX. Relationships between the Project PI and members of USAF (1st Lt A. Wehner) and members of NG-RAC (Mr. G. Loegering) are already established and will be expanded as needed to address Global Hawk issues as they arise.

The Project Coordinator will act as a liaison between NOAA, USAF, and NG-RAC to coordinate matters pertaining to the aircraft, and project teams during the preparation and deployment phases of GHATTEX. The Project PI will also directly interact with the project teams as needed to help guide the activities related to meeting the science objectives. The Project Coordinator will focus on the technical objectives of establishing payload performance and details of the field activities and the deployment participants. Each team member will have a responsibility to provide a timely response to management requests and timely input concerning matters that affect the ability of the team to meet the science and performance goals of GHATTEX.

The Instrument PIs are listed in **Table 3.2-1**. Each Instrument PI is broadly experienced in acquiring science-quality data in a team approach using aircraft platforms in the upper troposphere and lower stratosphere. Each Instrument PI has unique skills and experience related to their respective instrument. Each Instrument PI has the following responsibilities:

- prepare their respective instrument to be flight-ready to acquire science-quality data using a support team of their choice;
- work within the IPM to design, construct, and integrate their respective instrument and sampling inlet (if needed) on board Global Hawk;
- participate in reviews as requested;
- support their respective instrument during the field deployments for test and mission flights;
- prepare a final data set from each flight and make it available to the data archive and other investigators;
- analyze and interpret their instrument data in the context of other acquired data sets to address the science goals of GHATTEX; and
- cost and schedule control and reporting.

The Theory Team has been chosen to support the interpretation of the acquired data set and participate in predicting the conditions along proposed flight tracks as part of mission flight planning. Theory Team members responsibilities are:

- participate in the interpretation of the aircraft data sets as outlined by GHATTEX science objectives and as described in **Section 3.6.1**;
- participate in predicting the meteorological and chemical context of planned test and science flights; and
- cost and schedule monitoring and reporting.

The Education and Public Outreach Coordinator will be responsible for supervising all aspects of the proposed EPO activities. The Coordinator has extensive experience in planning, designing, implementing, and evaluating similar activities. Other EPO team members will include NOAA/AL, NOAA ERL, and EAFB staff with extensive experience in public outreach, and CIRES Outreach Program staff with extensive and specialized experience. The Coordinator's responsibilities are:

- to coordinate, plan, and carry out all aspects of the proposed outreach activities; and
- cost and schedule monitoring and reporting.

Members of NOAA/AL will provide technical support for the GPCC and for flight data archiving. The individuals providing this support have unique and considerable experience related to these particular tasks.

Other technical support be will provided by members of the USAF at Wright-Patterson AFB and of NG-RAC. The USAF will support and coordinate the use of the Global Hawk in GHATTEX on an as needed/as available basis. Similarly, one or more members of NG-RAC will support and help manage the modification, preparation, and use of the Global Hawk at NG-RAC. Mr. Greg Loegering is the principal NG-RAC contact. The management structure within NG-RAC and the USAF will be responsible for tasking its respective personnel to meet the accepted tasks. The joint NOAA/USAF/NG-RAC management structure will do periodic updates and assessments of progress and make any recommendations to maintain progress. The NG-RAC Statement of Work identifies and assigns all of the tasks associated with preparing and flying the Global Hawk in GHATTEX.

5.2 Work Breakdown Structure IP-Section 3.4

The Work Breakdown Structure (WBS) (**Figure 5.2-1**) shows the principal components of GHATTEX. The Level 2 components of the WBS are Project Management, Instrument Payload, Aircraft Support and Integration and Test, Operations and Mission Planning, Science, and Education and Public Outreach. The WBS components are described in the WBS Dictionary in **IP-Table 3.4-1**. The WBS tasks are nominally divided into pre-deployment, deployment, and post-deployment phases in **Figure 5.2-1**. NOAA, NG-RAC, USAF, and CIRES will share the IPM components (see **Figure 5.0-1**). The Instrument Payload components include all of the measurements and the payload computer (see **IP-Table 2.1-2**). The Aircraft Support component is subdivided into Payload Integration and Flight Test. The Level 3 categories include all principal aspects of the respective components. The Science component includes sublevel categories of data archiving, data analysis, and Science Team meetings. These encompass all aspects of the data analysis process.

The GHATTEX Project Schedule (**Figure 5.4-1**) shows the timeframes of the Level 2 and 3 components and sublevel categories through the three project phases. Some of the components range over more than one project phase. The project reviews and milestones: Kick-off, Critical Design Review, Flight Readiness Review, Deployment Readiness Review, Mission Flights, Science Report Delivery, are also shown in **Figure 5.4-1**.

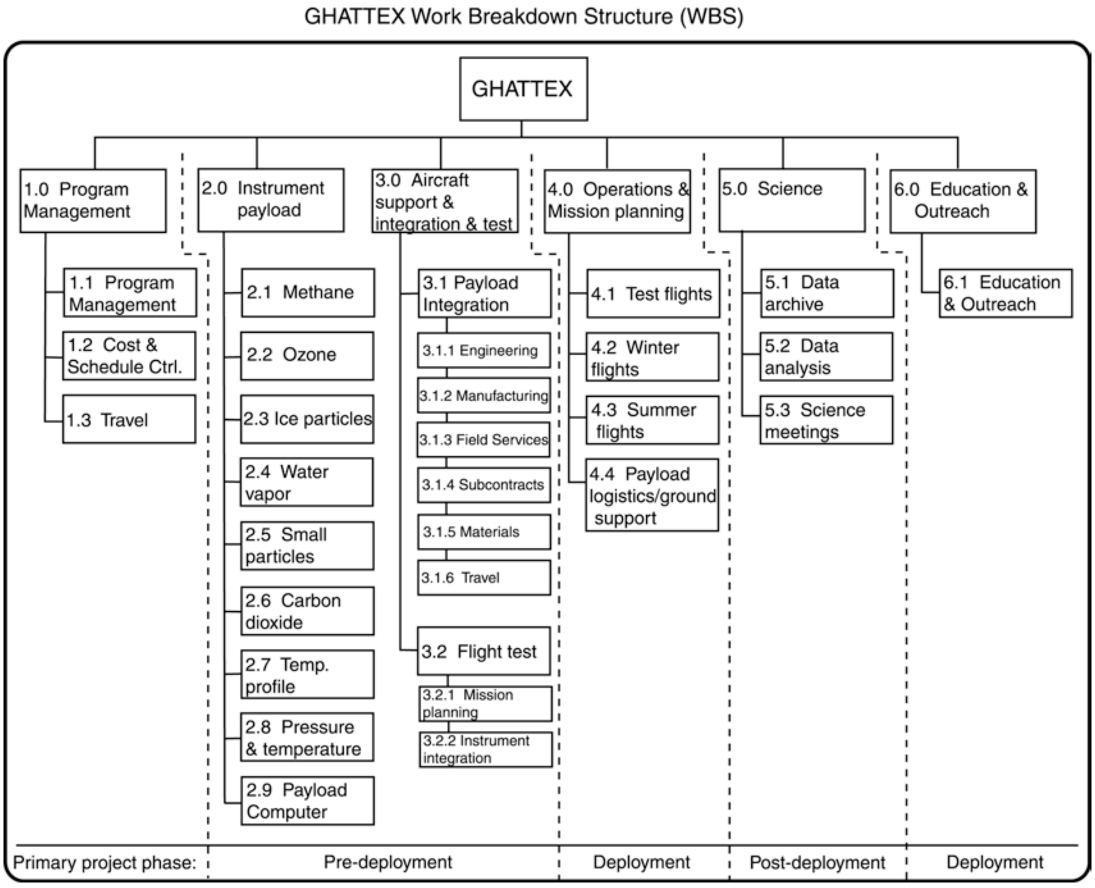

Figure 5.2-1 GHATTEX Work Breakdown Structure (WBS)

5.3 Project Control Plan IP-Section 3.5

The Project Control Plan embodies and administers the plans and processes that are used to define and execute GHATTEX. It includes managements of costs, contracts and configuration, and control of the schedule.

5.3.1 Plans and Requirements IP-Section 3.5.1

A well-structured series of management plans developed early in the project control all phases of the GHATTEX project. Documented processes support the plan with an emphasis on preventing rather than reacting to programmatic concerns.

The Project Plan (PP) describes the plans and processes used on GHATTEX. The PP describes how the GHATTEX project is carried out and serves as the controlling document for implementing the GHATTEX project throughout its life cycle. The PP will be prepared at the beginning of the project and is used as the primary guide for executing the project. The PP includes the following elements:

Project Plan Elements
Contracts and SOW
Work Authorization
Work Breakdown Structure
WBS Dictionary
Integrated Project Schedule
Project Reviews and Milestones
Project Organization and Management
System Engineering
Project Budgets and Earned Value Monitoring
Receivable/Deliverable List
Subcontracting
Resource Management and Control

The key to controlling cost and schedule is early definition, documentation, and freezing of top-level requirements, while retaining design flexibility at the subsystem level. At the beginning of the project, the project requirements are formally frozen to establish a technical baseline. GHATTEX has progressively traded technical performance against cost to provide a maximum value. Substantial margins in the Global Hawk capacities prevent mass, power, and volume from being cost and design drivers. Specification of requirements will continue in the design phase of the project. Subsystem requirements are adopted to meet optimized cost and schedule goals for a specified (fixed) performance level rather than to optimize each subsystem. This requires retaining subsystem-requirements flexibility throughout the design phase. With a high percentage of the hardware already existing, changes to technical requirements during the GHATTEX project will be minimal.

5.3.2 Cost Management IP-Section 3.5.2

Cost management control requires the maintenance of a baseline plan that remains fixed unless scope changes are approved. This enables a meaningful tracking of cost and schedule variances.

Accumulation of actual costs occurs monthly at Level 3 of the WBS. GHATTEX uses an integrated set of charts, graphs and tables to display the current, past, and predicted future cost and schedule variances using standard earned value system (EVS) techniques. The EVS compares task completion against milestones associated with selected WBS elements. WBS elements are selected for EVS monitoring based on current activity and budget thresholds. Level of effort tasks such as payload integration are compared to the time-phased budget plan. Each element has an earned value attached to its completion status; actual expense is compared to planned expense at any time. The value of incomplete (slipped) work can be readily determined. Slipped work represents unplanned expense to complete, and must be mitigated through recalculation of the planned expense profile or the schedule. The Project PI does this on recommendation from the technical staff and contracting officers in NOAA/AL and can involve allocation of budget or schedule reserves.

Responsible task leaders will analyze cost status and trends for their respective elements. As a minimum, the IPM members convey cost concerns to the Project PI during monthly management reviews and more frequently, if appropriate. Independent project level cost analysis is performed by the Project Coordinator who reports any issues and concerns to the Project PI and IPM team leaders. The variance information is utilized by the IPM team leaders to evaluate programmatic status, and take corrective actions if warranted.

As part of its reserve management program, GHATTEX compares the monthly EVS cost and schedule reports to the budget plan in order to produce estimates of cost at completion. These figures are compared to the project baseline to validate the team's assessment of current project status, remaining efforts, and appropriate use of reserves.

5.3.3 Schedule Control *IP-Section 3.5.3*

The GHATTEX Project Schedule is shown in **Figure 5.4-1**. Schedule management uses proven tools such as Microsoft Project, providing the project managers with sufficient insight into scheduling issues to detect and mitigate problems early. The Project PI has overall schedule responsibility and will be supported by the top-level IPM managers.

This schedule is updated at the beginning of the project upon completion of the detailed project network. Each individual within the IPM has his or her own schedule that, while consistent with this overall schedule, lays out events and activities in the most convenient and efficient format for his or her particular effort.

Microsoft Project software is used to generate the networks. It has been successfully used on other programs within NOAA/AL. The integrated network, to be completed after project start, identifies the timing for the highest level receivables/deliverables. It readily allows project assessment of any accomplishment deficiency and evaluation of alternative recovery scenarios for IMP consideration and action.

The complete Microsoft Project schedule network defines the work dependencies, the critical path, and the amount of slack in non-critical paths based on inputs of task duration and key anchor dates. The network also defines all of the schedule margin periods in the total project flow and facilitates proactive management of the margin. Schedule output is displayed as a network or Gantt-type charts.

Detailed subsystem schedules have been developed for all hardware, software, and integration elements. Detailed subassembly and program network schedules are developed for the GHATTEX project. Microsoft Project, along with a standard suite of software products, will be used throughout on the project. Subsystem schedules will be rolled-up into one master project schedule, which will then be coordinated and transmitted electronically. The detailed schedule is also the foundation of the GHATTEX performance measurement system.

Schedule reserves are budgeted for each subsystem in addition to the project-wide slack. Potential scope changes identified in the project plan provide additional schedule margin and recovery options for IMP consideration and action.

5.3.4 Contract Management *IP-Section 3.5.4*

The NOAA contract manager allocates funding to its research partners and is funded by NASA directly (see **Appendix E**). The Project PI acts as the GHATTEX project manager and is responsible for the performance of the contract, and any and all changes that may occur.

5.3.5 Configuration Management *IP-Section 3.5.5*

The Project PI, in conjunction with the IPM team leaders, defines the configuration program for GHATTEX and documents the policy and procedures. The plan addresses our simple method for controlling changes across systems and organizational boundaries. Configuration management is carried out using the existing practices within the performing organizations.

5.3.6 Project Assessment *IP-Section 3.5.6*

The assessment of the GHATTEX Project has two aspects. The first is the continuing process by which the Project PI monitors the project as it evolves, using the techniques described above. The scientific assessment of the GHATTEX project at completion will be embodied in the GHATTEX Science Report **(Figure 5.4-1)**. Its production will be a joint activity of the Science Team led by the Project PI.

5.4 Schedule IP-Section 3.2

The GHATTEX Project Schedule is shown in **Figure 5.4-1**. The major scheduled tasks map to the WBS Level 2 tasks (**Figure 5.2-1**). Important reviews, milestones and project phases (pre-deployment, deployment, and post-deployment) are included (see listing in **IP-Section 3.2.1**). Linkages between tasks show the critical path. Start and end dates for tasks are shown along with duration in business days.

Our schedule management process implements:

- planning in early stages to define and understand the work;
- inserting slack and risk mitigation into the baseline plan;
- monitoring performance and updating predictions based on historical performance; and
- reacting immediately to recover delays.

Initial planning for GHATTEX has been accomplished and is captured in our integrated project schedule (**Figure 5.4-1**). This baseline includes funded slack and risk mitigation plans and key decision dates before proceeding to the next phase. During the program, performance against this baseline is continually monitored across all program elements through weekly and monthly meetings. The tools used for schedule management are Microsoft Project and a variety of other software programs.

The team's resources are available to quickly address and resolve problems. Techniques for recovering schedule slips include replanning and rearranging tasks to work around obstacles, applying additional resources (e.g., personnel, facilities, cost reserves), and modifying individual tasks to maintain system schedule. Resources from throughout the team are shared wherever necessary to maintain schedule progress.

A compelling majority of the GHATTEX schedule time frames are highly certain and predictable by virtue of being anchored in the teams' actual performance history. This allows for flexibility in the development of cost and schedule reserves.

Specific margins and reserves will be built into the baseline plan and allocated according to the perceived risk of a problem, whether cost, schedule, or technical. This management approach builds resiliency into our baseline plan.

We are planning a phased release of schedule reserve when required during the project life cycle. The Project Coordinator maintains schedule metrics to provide a constant assessment of the health of the project to the Project PI. Our schedule reserve will be funded, so that use of the schedule reserve to solve unforeseen development problems does not directly impact cost or technical performance.

5.5 Project Risk Assessment and Management Plan IP-Section 3.6

Risk management is a disciplined, well-defined and continuous system engineering process that identifies risks, analyzes their impact, prioritizes them according to their impact, and then develops and carries out plans for mitigation of those risks that have a critical impact on the success of the project. Our risk management approach uses three major categories or levels of risk, and these three are summarized in **IP-Table 3.6-1**.

Our specific approach to risk management for GHATTEX consists of four primary steps:

1) Risk identification: A survey of all areas of the project is performed and potential areas of risk are defined; this process is repeated as necessary to ensure that all risks are systematically identified.
2) Risk assessment: Once the risk identification survey has been completed, each risk is assessed as to its impact on the scope, schedule and budget available, on its probability of occurrence, and on the consequence of occurrence. A summary of the initial risk identification survey is shown in **IP-Table 3.6-3**.
3) Risk Mitigation Plan Generation: A mitigation plan is then developed for those items with a risk level of medium or higher. The plan consists of a number of "Risk Mitigation Waterfall Charts" showing the time history of the assessed risk at each critical milestone of the project. The charts also depict the specific actions taken in order to get to a lower level of risk.
4) Risk Management: Management of risk periodically tracks the progress of the risk mitigation tasks identified on the waterfall charts and provides management control in order to ensure that the risks are reduced to acceptable levels.

ID	Task Name	Duration	Start	Finish
1	**Major Program Milestones**	**804 da**	**Tue 5/1/**	**Mon 5/31/**
2	Contract Award	0 day	Tue 5/1/0	Tue 5/1/0
3	Contract Start	0 day	Fri 6/1/0	Fri 6/1/0
4	Critical Design Review	0 day	Fri 11/30/	Fri 11/30/
5	APMP Delivery to NOAA	0 day	Fri 3/1/0	Fri 3/1/0
6	Instrumented APMP Returns to NG-RAC	0 day	Mon 6/3/0	Mon 6/3/0
7	Flight Readiness Review	0 day	Tue 8/20/	Tue 8/20/
8	Test Flight Readiness Review	0 day	Mon 9/2/0	Mon 9/2/0
9	NASA Safety Review	0 day	Mon 9/2/0	Mon 9/2/0
10	Deployment Readiness Review (DRR)	0 day	Mon 9/2/0	Mon 9/2/0
11	Local Test Flights Begin	0 day	Tue 9/3/0	Tue 9/3/0
12	Science Readiness Review	0 day	Fri 11/1/0	Fri 11/1/0
13	First Flight DRR	0 day	Fri 11/8/0	Fri 11/8/0
14	Second Flight DRR	0 day	Tue 6/24/	Tue 6/24/
15	Third Flight DRR	0 day	Mon 11/3/0	Mon 11/3/0
16	Science Report	0 day	Mon 5/31/0	Mon 5/31/0
17	Project Completion	0 day	Mon 5/31/0	Mon 5/31/0
18	**Project Phases**	**782 da**	**Fri 6/1/**	**Mon 5/31/**
19	Pre-deployment	326 day	Fri 6/1/0	Fri 8/30/0
20	Deployment	274 day	Mon 9/2/0	Thu 9/18/
21	Post-deployment	182 day	Fri 9/19/0	Mon 5/31/0
22	**Instrument Integration**	**262 da**	**Fri 6/1/**	**Mon 6/3/**
23	Methane	241 day	Fri 6/1/0	Fri 5/3/0
24	Ozone	241 day	Fri 6/1/0	Fri 5/3/0
25	Ice Particles	241 day	Fri 6/1/0	Fri 5/3/0
26	Water Vapor	241 day	Fri 6/1/0	Fri 5/3/0
27	Small Particles	241 day	Fri 6/1/0	Fri 5/3/0
28	**Carbon Dioxide**	**241 da**	**Fri 6/1/**	**Fri 5/3/**
29	Design	125 day	Fri 6/1/0	Thu 11/22/
30	Fabrication & Assembly	84 day	Fri 11/23/	Wed 3/20/
31	Test	32 day	Thu 3/21/	Fri 5/3/0
32	Temperature Profiler	241 day	Fri 6/1/0	Fri 5/3/0
33	Pressure & Temperature	241 day	Fri 6/1/0	Fri 5/3/0
34	**Payload Computer**	**241 da**	**Fri 6/1/**	**Fri 5/3/**
35	Design	125 day	Fri 6/1/0	Thu 11/22/
36	Fabrication & Assembly	84 day	Fri 11/23/	Wed 3/20/
37	Test	32 day	Thu 3/21/	Fri 5/3/0
38	Schedule Reserve	20 day	Mon 5/6/0	Fri 5/31/0
39	Instruments Complete	0 day	Fri 5/31/0	Fri 5/31/0
40	Integration to APMP	66 day	Fri 3/1/0	Fri 5/31/0
41	APMP Delivery to NG-RAC	1 day	Mon 6/3/0	Mon 6/3/0
42	**Aircraft Support**	**306 da**	**Mon 7/2/**	**Mon 9/2/**
43	Requirements Development	33 day	Mon 7/2/0	Wed 8/15/
44	Release Preliminary ICD	0 day	Wed 8/15/	Wed 8/15/
45	**Integration**	**228 da**	**Thu 8/16/**	**Mon 7/1/**
46	Analysis & Flight Control	87 day	Thu 8/16/	Fri 12/14/
47	Mechanical	141 day	Thu 8/16/	Thu 2/28/
48	Software	207 day	Thu 8/16/	Fri 5/31/0
49	Electrical	121 day	Thu 8/16/	Thu 1/31/
50	Fabrication & Assembly	64 day	Mon 12/3/0	Thu 2/28/
51	Test	208 day	Thu 8/16/	Mon 6/3/0
52	Simulator Test @ NG-RAC	20 day	Tue 6/4/0	Mon 7/1/0
53	Schedule Reserve	10 day	Tue 7/2/0	Mon 7/15/0
54	Test & Checks @ EAFB	35 day	Tue 7/16/	Mon 9/2/0
55	**Operations**	**710 da**	**Fri 6/1/**	**Thu 2/19/**
56	**Mission Planning**	**710 da**	**Fri 6/1/**	**Thu 2/19/**
57	Preliminary Planning	327 day	Fri 6/1/0	Mon 9/2/0
58	Test Flights	15 day	Tue 9/3/0	Mon 9/23/0
59	Reserve	5 day	Tue 9/24/	Mon 9/30/0
60	Primary Winter Flight Window	90 day	Fri 11/15/	Thu 3/20/
61	Primary Summer Flight Window	58 day	Tue 7/1/0	Thu 9/18/
62	Backup Winter Flight Window	69 day	Mon 11/17/	Thu 2/19/
63	Payload Logistics/Ground Support	449 day	Mon 6/3/0	Thu 2/19/
64	Science Data/Analysis/Archive	455 day	Tue 9/3/0	Mon 5/31/0
65	Education/Public Outreach	782 day	Fri 6/1/0	Mon 5/31/0

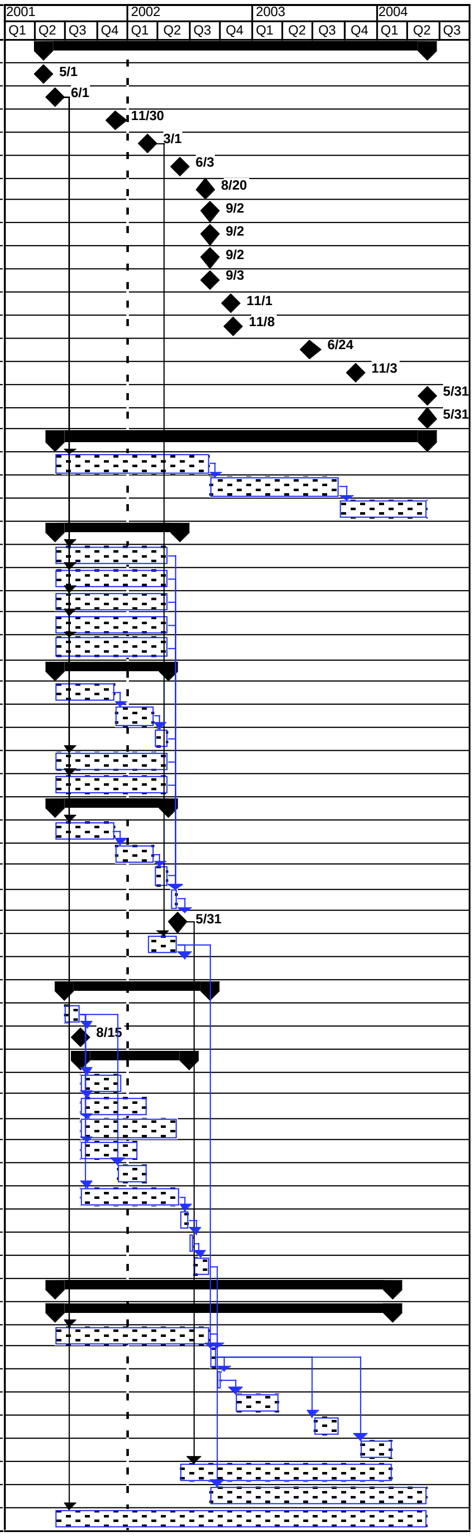

Figure 5.4-1 GHATTEX Project Schedule

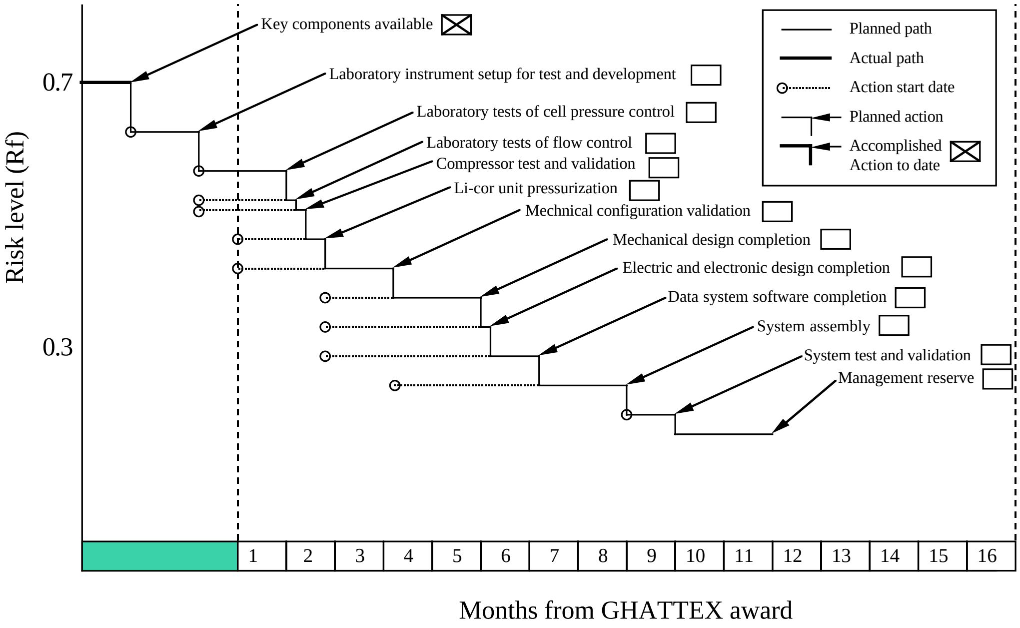

Figure 5.5-1 Risk mitigation plan (waterfall chart) for the CO_2 instrument

The worksheet shown in **IP-Table 3.6-2** was used by the Project Team to aid in the assessment of the risk of the individual items contained in the WBS, and **IP-Table 3.6-3** contains a summary of the assessment made using the worksheet. **IP-Appendix M** contains all of the individual worksheets filled out by the team for the GHATTEX risk assessment including the documentation of the guidelines used in assigning the numerical values of the worksheet itself.

The integration of the existing payload instruments onto the Global Hawk is considered low risk because the payload margins of weight, volume, and power are large (**IP-Table 2.3-2**) and the technical and Instrument-PI teams have considerable experience with the associated tasks. According to our analysis the new CO_2 instrument and the GPCC are medium risk items and require the generation of a waterfall chart for risk mitigation (see **Figure 5.5-1** and **IP-Figure 3.6-2**). The following sections summarize the plans to mitigate risk for both of these medium-risk items before payload integration completion. All other tasks are low risk.

5.5.1 Carbon Dioxide Instrument Risk Mitigation Plan *IP-Section 3.6.1*

The detailed waterfall chart is shown in **Figure 5.5-1** to mitigate the risk associated with building the CO_2 instrument. The waterfall chart shows how risk from software and hardware maturity will be reduced over the integration period to provide an overall low risk (see **IP-Appendix M**). There is a two-month management reserve in the schedule with a further five months before the first test flight. The cardinal points are (i) the instrument design closely resembles an existing NOAA CO_2 instrument which is mission-proven on the WP-3D aircraft and (ii) that there is substantial schedule reserve. The GHATTEX Project Schedule (**Figure 5.4-1**) shows the tasks associated with the instrument building.

5.5.2 GHATTEX Payload Control Computer (GPCC) Risk Mitigation Plan *IP-Section 3.6.2*

The detailed waterfall chart is shown in **IP-Figure 3.6-2** to mitigate the risk associated with building the GPCC computer. The GHATTEX Project Schedule (**Figure 5.4-1**) shows the tasks associated with the computer building. The waterfall chart shows how risk from software and hardware maturity will be reduced over the integration period to provide an overall low risk (see **IP-Appendix M**). It is important to note that the GPCC is to function as the electrical and electronic interface between the established, and proven payload instruments and an established and proven airframe. Standard buses and protocols are to be used; there will be eight months of time available to test and operate the interface with the payload before the test flights. The engineer responsible for this item, Mr. T. L. Thompson, has over 20 years experience in interfacing these and similar instruments with the U-2, ER-2 and WB-57F aircraft, and indeed designed the electronics and coded the software for several of them.

5.5.3 Mitigation of Risk Arising from Global Hawk Availability IP-Section 3.6.3

There is risk in the availability of the Global Hawk should the USAF have a high priority call for it in the event of a world crisis. In the absence of a crisis, GHATTEX has the full support of the USAF as the only external Global Hawk project that has received approval out of many requests. If there were a crisis during which Global Hawk was unavailable, the response would be a slippage of the entire remaining GHATTEX schedule from the date of the priority call. There is scope for such mitigating slippage, depending upon when the priority call removed availability of the Global Hawk. The schedule calls for completion of the flights on 18 September 2003 whereas the project finishes on 31 May 2004, allowing up to 8.5 months of slippage. Because such an event is an overarching risk, it is discussed separately here rather than in the detailed sections below. The precise impact of such an event would depend on when it occurred. The scope risk is obvious; however, it could lead to a complete loss of all GHATTEX flights only if the aircraft was unavailable from the test flights, which begin 3 September 2002, to the end of the project, 31 May 2004, a period of 21 months. If there were no flights, there would be a budgetary impact, basically a saving of all the flight and deployment costs. As a consequence of our schedule flexibility and the close cooperation with the USAF that is inherent in GHATTEX, we consider the risk associated with Global Hawk availability to be low.

A conservative approach by the USAF to Global Hawk flights across large ocean tracks has led to airframe #5 being fitted with International Maritime Satellite (INMARSAT) capability as a second independent satellite communication link. In order to mitigate risk to GHATTEX, provision has been made for reserve funding to install INMARSAT capability on a second airframe. This reserve would be used only in the event that airframe #5 becomes unavailable for GHATTEX.

The calculated Global Hawk Critical Reliability is 1 aircraft loss in 541 flights (thereby defining Mean Flight to Loss (MFTL)), where a flight is assumed to be 42 hours long. This yields a reliability of 0.99815 and corresponds to 22682 hours of mean time to critical failure (MTTCF; a failure rate of 4.40E-05). The flight critical reliability analysis followed a standard methodology for predicting the air vehicle probability of survival, and the details of the analysis can be found in the NG-RAC Document Number 367-4100-058.

5.5.4 Risk in the Pre-Deployment Phase IP-Section 3.6.4

Risk to scope. The scope risk in this phase lies essentially in whether the proposed payload can be integrated on to the Global Hawk. Because the margins in mass, volume and power are large (see **IP-Table 2.3-2** and **Section 4.1.1)** we see no risk that any of these factors will prove limiting.

Risk to schedule. The schedule risk in this phase comes from preparation of the payload. It is largely in the production, testing and integration of the two medium risk items, the CO_2 instrument and the GPCC; the mitigation of these is discussed above in **Sections 5.5.2** and **5.5.3** respectively. Schedule and cost reserves will be used to mitigate risk as needed.

Risk to budget. The budgetary risk in the pre-deployment phase is largely that connected with the payload integration, which includes the design, manufacture and test for form, fit and function of the mechanical and electrical interfaces between the Global Hawk and the payload. The tasks outlined in the NG-RAC SOW (**IP-Appendix N)** are to be fulfilled by NG-RAC under contract. The NG-RAC cost proposal is based on very detailed WBS and Task ID analysis, and the tasks do not involve any major innovations or impacts on the structure and shape of either the Global Hawk or the payload. NOAA/AL's proposed budget does have provision of reserves in connection with the NG-RAC contract, as shown in the cost summary (see **Appendix E**). With regard to the medium-risk payload items, CO_2 and GPCC, adequate cost reserves are included in the budget. Should this not be the case, NOAA/AL will assume responsibility for completing the design and construction of the CO_2 instrument and GPCC.

5.5.5 Risk in the Deployment Phase IP-Section 3.6.5

Risk to scope. The scope risk during deployment can arise from malfunctioning of the Global Hawk or malfunctioning of the payload, or conceivably from weather conditions outside limits for landing and take-off. The existing track record of the Global Hawk operating from EAFB indicates that both malfunction and local weather conditions are in the low risk category as regards scope, since such delays will be short enough that while flights might be delayed, they would not be cancelled. Payload function affects the aircraft take-off decision as described by the go/no-go criteria (see **Figure 4.3-2** and **Section 4.3.3)**, and manages the scope risk. It would apply during the 25- and 32- hour flights as well as before take-off. The risk is in the low category.

The scope risk arising from the Global Hawk's altitude and time-at-altitude capabilities is very small. The performance of the Global Hawk as measured by the combination of duration, range, altitude, and payload (see **Section 3.3**) is to our knowledge unrivalled. The performance has been demonstrated in 759.1 hours of flight time (**IP-Appendix D**). The range of 11,000 nautical miles means that the radius of action from EAFB is one quarter of the Earth's circumference. The turnaround time between flights is 1 to 2 days. This, together with the issues of availability, payload mass, volume and power, and weather capability in the context of conditions at EAFB which are dealt with elsewhere in this section, mean that the risk to mission accomplishment arising from the Global Hawk's characteristics is small. By the time of the GHATTEX deployment phase, USAF flight operations will have demonstrated performance in the GHATTEX regions in the tropical Pacific.

There is scope risk in the deployment phase, arising from the scope option of omitting the summer flights, leaving only the test flights and winter flights (see **Section 3.5.1**).

Risk to schedule. During the deployment phase, the schedule risk arises from functionality of platform and payload, and from weather conditions at EAFB for take-off and landing. Because there is one-week contingency for each window (test flights and science flights (see **Figure 5.4-1**), and because there are 90 and 58 day windows for the pairs of winter and summer flights, we see little schedule risk associated with the science flights. This situation is further mitigated by a 69-day backup window for winter flights. The schedule risk arising from the possible occurrence of unforeseen problems during the test flights is accommodated by having a 3-week period with a 1-week contingency reserve to accommodate 24 hours of test flights. Since the platform and payload are proven, this too is a low risk item.

Risk to budget. The budget risk in the deployment phase consists largely of the travel and subsistence costs of the GHATTEX Project Team at EAFB, and is readily quantifiable (item 1.3, GHATTEX WBS, **Section 5.2**, **Figure 5.2-1**). Should the test flights and science flights be successfully executed early in their respective windows, savings will accrue.

5.5.6 Risk in the Post-Deployment Phase *IP-Section 3.6.6*

In the absence of the second scope option (see **Section 3.5.1**), the entire activity in the post-deployment phase is low risk, because of the quality of the Science Team and because of the existence of much pre-tested and successfully used analytical and scientific software. If the second scope option is adopted, half the Science Data/Analysis/Archive activity GHATTEX Project Schedule (**Figure 5.4-1**) would be omitted. There would be a substantial loss of scientific return arising from such an action, but the risk to the production and archival of the science quality data would be low, since all the mechanisms by which it is to be achieved have been exercised many times during ER-2 and WB-57F missions. This scope option would truncate the project schedule by 6 months, and in so doing would result in substantial cost reduction, as intended.

5.5.7 Margins and Reserves *IP-Section 3.6.7*

The allowances made for margins and reserves were determined by considering the results of the risk analysis described in the preceding parts of **Section 5.5**. The considerations reflect up to 17 years of experience with the payload instruments and three years of flight experience with the Global Hawk. The allowances use the risk assessment worksheets shown in **IP-Tables 3.6-1** and **3.6-2** and **IP-Appendix M**.

The margins and reserves in the schedule are conservative. This was made possible by the proven performance of the platform and of the payload, and is enhanced by the six-month separation between the winter and summer deployments. NOAA/AL's acceptance of the cost liability for the design and construction of the new CO_2 instrument and GPCC substantially reduces the cost risk of completing the GHATTEX payload. Finally, there is an eight-month period at the end of the project in which a backup winter flight window is scheduled.

The GHATTEX budget will include reserves for the payload integration phase. Reserves will be available for completing and integrating the two medium risk items on to the Global Hawk. Budgetary allowance has also been made to accommodate the one-week reserve that is included in each of the three deployments. Management of these reserves will be on the basis of the earned value system reporting.

Because the payload integration phase occurs early in the GHATTEX Project, there will be time to consider scope options if necessary, such as cutting the later stages of the project activity: the summer flights and the data analysis. If the margins and reserves are not consumed during payload integration, it will be possible to expand the margins and reserves for the later flight phases, even though these are low risk activities.

5.6 Liability Assessment and Management Plan IP-Section 3.7

Liability, per the NASA safety policy for the use of military operated and owned aircraft has been handled per a memorandum of agreement between the Global Hawk Systems Program Office, U.S. Department of Defense, and the NOAA Aeronomy Laboratory, U.S. Department of Commerce. See **IP-Appendix J** for a copy of the applicable MOA.

The liability management will be within the rules set for the Federal Government, which insures itself. The Global Hawk will be operated under the assumptions that govern the USAF fleet, i.e., that the USAF deals with liability. The payload instruments will be operated under the same assumptions that have governed their operation on NASA, NOAA, and NSF aircraft during their extensive past history; namely, that the owners of the instruments will not seek recompense from the owners of the aircraft in the event of loss. Each institution will be responsible for its own instrument(s).

NOAA/AL does not accept liability for the cost and schedule performance of GHATTEX participants outside NOAA/AL. NOAA/AL does accept liability for the tasks related to NOAA/AL payload instruments and data archiving. This applies to the design and construction of the new CO_2 instrument and GPCC by NOAA/AL staff. The Project PI and Co-PI, however, do accept responsibility for monitoring the cost and schedule performance of all aspects of the project, for providing feedback to the participants concerning cost and schedule performance, for identifying strategies to mitigate cost and schedule problems, and for allocating cost reserves to assist in the mitigation.

6.0 Cost Plan and Supporting Documentation

The GHATTEX cost plan is based on detailed cost information from NOAA/AL and other participating institutions. Project total costs and separate institutional costs are summarized in **Table ES-1** in the Executive Summary. The breakdown of project costs is shown in **Appendix E** in **Table 1**, Total Mission Cost Funding Profile; **Table 2**, Phase Cost Breakdown by WBS and Major Cost Category Template; and **Table 3**, Phase Cost Breakdown by WBS. Short Work Package Agreement (SWPA) forms are also included for each institution along with a statement of indirect cost schedules. Other issues related to the cost plan are discussed in the following sections.

As presented in **Tables 1, 2, and 3**, the total GHATTEX cost to NASA is $**** (RY$). With the addition of $****, the sum of *in-kind* contributions from NOAA/AL and CIRES, the total program cost is $****. Costs were developed by NOAA/AL; University of Denver; University of Colorado; MIT; Particle Metrics, Inc.; Northrop Grumman-RAC; Department of the Air Force; and JPL personnel familiar with other recent program cost histories. We understand the costs at a detailed level and use proven, effective control methods, such as the Earned Value System and Critical Path Scheduling, to ensure that the as-delivered cost meets the proposed cost.

During the final stages of budget definition, the USAF decided that it was necessary to mitigate risk to GHATTEX by having the provision of cost reserves to equip a second Global Hawk airframe with INMARSAT capability (see **Section 5.5.3**). This led to an increase of $**** in the NG-RAC cost, all of it reserve. Similarly, the increase of the total USAF cost to $**** is attributable largely to the provision of very conservative cost reserves for risk mitigation. In the case that Global Hawk Airframe #5 is not available and the $**** NG-RAC cost reserve is used to install INMARSAT on a second airframe, the total NASA proposed cost can be contained to $**** by reducing the data analysis period as discussed in the scope options (see **Section 3.5.1**).

6.0.1 Cost Estimating Methodology

General Cost Estimating Methodology. Upon receipt of the proposal instructions the Project PI reviewed the scope of work, analyzed the requirements, and evaluated how the work would be performed by NOAA/AL. After this was accomplished, the Project PI contacted the IPM team leaders (estimators) and knowledgeable individuals to develop a task concept and strategy, complete the analyses, and provide technical and cost inputs to the proposal. **IP-Figure 4.1.2-1** illustrates the process NOAA will use to provide a thorough review of the GHATTEX project and ensure a detailed, accurate, and complete technical and cost proposal.

Both technical and cost inputs are based on the GHATTEX Project Schedule, hardware specifications, data requirements, statement of work, and other governing documents contained or referenced in the proposal instructions. These dictate the WBS, WBS task descriptions, and task schedules that are the starting point for the detailed cost estimates. The estimators are responsible for evaluating the level of detail of work, the required subtasks, the similarity to previous efforts with which they are familiar, selecting the basis of estimate, and generating the baseline estimate for their work effort.

All applicable elements of cost have been identified, (i.e. labor, materials, travel, other direct costs), and estimated by element for the lowest WBS level where the tasks could be defined in detail. Data from the detailed cost estimates have been entered into the appropriate spreadsheets for analysis and submittal. Special parts and subcontract estimates have been solicited from vendors. From these direct cost estimates, a time-phased budget has been prepared.

The Project PI reviewed these estimates for accuracy and completeness as they were received from the IPM team leaders. The Project PI has conducted further review for consistency with the task concept and strategy. A final review has been conducted with the NOAA/AL Laboratory Director to approve the above and to ensure compliance with the GHATTEX proposal directives.

Northrop Grumman Ryan Aeronautical Center. Pricing provided by NG-RAC for all direct charges is based on estimates, some of which were supported by historical actual costs. NG-RAC's estimates reflect judgments by the various performing organizations (and/or the Pricing Department) as reviewed and adjusted by Management. Among the factors taken into account in NG-RAC's estimating process are the risk and uncertainties associated with the type of effort requested by NOAA’s Statement of Work (SOW) to NG-RAC in such areas as material (e.g., configuration changes), schedule, labor productivity, etc (see **IP-Appendix N** for a copy of the SOW from NOAA to Northrop Grumman for performing GHATTEX). The cost proposal provided to NOAA by NG-RAC was not the company’s most optimistic estimate of the cost of performing the work under the most favorable of circumstances, but represents an amount within which NG-RAC's management believes that the company has a reasonable likelihood of completing the work in view of the schedule, technical requirements, business situation and other circumstances.

Labor estimates were based on grass roots estimates developed by the functional groups responsible for the various tasks defined in the SOW. These cost estimates are entered onto a NG-RAC standard form, and includes all labor costs, material costs and travel costs per department per task. The project lead at NG-RAC collects the filled out forms, reviews them, makes changes as necessary and often in consultation with the functional engineering lead, and then submits them to pricing. Pricing then uses a standard methodology for applying labor rates, overhead rates, capital costs of money and profit, and produces a cost proposal. The generated cost proposal is then reviewed by NG-RAC's management including the Global Hawk Program Director, the Global Hawk Business Manager and the project lead to ensure that the appropriate assumptions were used, that all specified tasks were adequately covered by the functional engineering leads and that the cost estimates are reasonable.

6.0.2 Cost Methodology Basis and Heritage

All GHATTEX subsystems have a strong basis and substantial heritage for cost methodology. GHATTEX subsystems include the eight instruments and the GPCC of the science payload, the Global Hawk modifications and operations, data analysis, and Education and Public Outreach activities.

Seven of the eight payload instruments have flown extensively on other high-altitude aircraft in other airborne projects. All instrument PIs have participated extensively in similar airborne projects with the GHATTEX or related instruments. The instrument techniques and flight heritage are briefly described in **IP-Section 2.1.2.1.** The eighth instrument, CO_2, will be designed and constructed following the successful approach for another CO_2 instrument on another NOAA aircraft (see **IP-Section 2.1.2.1**). The integration tasks for the GHATTEX Global Hawk configuration and flight plans are described in **Section 2.3.3**. The GHATTEX tasks are similar to those undertaken during the design, construction, and use of these working instruments. The identification of integration costs are therefore based on experience with working instruments on the ground and on board other airborne platforms.

The GHATTEX Project PI and Co-PI have extensive experience with airborne projects involving the NASA ER-2 and WB-57F aircraft. Responsibilities include the Project PI and instrument PI roles. NOAA/AL original estimates for their participation in the STEP, AAOE, AASE, AASE II, SPADE, ASHOE/MAESA, STRAT, POLARIS, and SOLVE missions with the NASA ER-2 were within the actual outturns to within a few percent. No funds for cost overruns were requested from NASA. The GHATTEX Project PI was also PI for the WB-57F Aerosol Mission (WAM). WAM was a PI-mode project that was highly successful and completed within the budget requested from NASA's UARP and AEAP. The GPCC design and construction follows the general approach guidelines used for other computers used in autonomous aircraft and balloon instruments in NOAA/AL over the last two decades. The GPCC is described in **Section 2.3.3.8**. The experience with control and date acquisition for the NOAA/AL aircraft instruments on the NASA ER-2 is particularly relevant. The GPCC cost estimates are based on this substantial heritage of previous instrument computers.

Northrop Grumman Ryan Aeronautical Center (NG-RAC) is the original and sole manufacturer and operator of the Global Hawk UAV. GHATTEX requires modifications to the SAR antenna payload bay, mechanical and electrical integration of the science payload instruments, and integration of payload command and control features into the aircraft electronic systems. The NG-RAC cost estimates are based on the engineering experience of manufacturing the aircraft and conducting flight tests which have accumulated 760 airframe flight hours.

Analysis of GHATTEX data and data archive activities will be carried out by the science and support team, which includes Instrument PIs and theory investigators. All have extensive experience analyzing aircraft data sets in a meteorological context using various atmospheric models. The cost estimates will be based on this extensive prior experience.

Education and Public Outreach (EPO) activities will be coordinated in GHATTEX by personnel with extensive experience in EPO activities. Cost estimates are derived from this experience and from estimates provided by EPO professionals at cooperating institutions.

Management of the GHATTEX project will be the responsibility of the GHATTEX PI with the support of the Project Co-PI, Project Coordinator, and other team members. The PIs and Project Coordinator have extensive experience in the management of aircraft field activities during the integration, deployment, and post-deployment phases. Cost estimates for management activities are based on this substantial collective experience.

6.0.3 Reserves

Reserves are allocated to cost, and schedule. These are released in each of the three phases of the project. Our cost reserve is sufficient to accommodate underestimates historically encountered **(Table 6.0-1)**. This reserve is 16.3% and is commensurate with our assessment of the program risk. Since the NG-RAC and USAF tasks are both related to the modification and operation of the Global Hawk UAV, the cost reserves will be effectively combined for the overall task. Thus, an 22% cost reserve ($****) is available for the combined cost of $**** of the USAF and NG-RAC tasks. Note that a substantial sum of the NG-RAC reserve, $****, will be used only if it is necessary to equip a second airframe with INMARSAT capability.

6.0.4 Funding Profile

The GHATTEX funding profile fits within the funding profile as outlined in the proposal instructions. Over the life of the program, the cost profile of GHATTEX requires 53.7% of the available program funding, allowing a high value of return for the funding spent. This fraction reduces to 49.6% if the INMARSAT reserve is unused.

6.0.5 Cost Reporting

In addition to the extensive Project Control Plan of GHATTEX (see **Section 5.3**), a formal cost report will be provided to NASA on a monthly basis. A 533M form will be generated on a monthly basis and forwarded to NASA for review. The cost inputs will be provided by each of the GHATTEX partners and compared against the cost and schedule baseline as a formal presentation of our programmatic controls. The budget includes provision for a professional cost accountant to spend four hours per month to prepare GHATTEX reports required by the Project PI and NASA.

Table 6.0-1. GHATTEX budget reserves (Numbers removed for distribution (Jan. 2007))

Institution	**NASA budget request (K$)**	**Reserve (%)**	**Reserve (K$)**
NOAA Aeronomy Laboratory	****	****	****
University of Denver	****	****	****
NASA Jet Propulsion Laboratory	****	****	****
Particle Metrics, Inc.	****	****	****
Massachusetts Institute of Technology	****	****	****
Education and Public Outreach	****	****	****
Northrop Grumman-Ryan Aeronautical Center	****	****	****
]U.S. Air Force ASC/RAV	****	****	****
Theory team travel	****	****	****
Total	****	****	****

6.0.6 Contractual and Financial Relationships

The contractual and financial relationships within GHATTEX are the following:

- NOAA/AL will be the sole recipient of funds from NASA ESE for GHATTEX;
- Program funding will be distributed as outlined in the formal GHATTEX budget proposal as accepted by NASA ESE;
- NOAA/AL will distribute and allocate a certain fraction of received funds for instrument teams, data archiving, project coordinator, and other support;
- NOAA/AL will let subcontracts through NOAA's Mountain States Administrative Support Center (MASC) to the following institutions:
  - USAF for costs associated with Global Hawk modifications and operations (use existing funding mechanism with NG-RAC);
  - University of Denver, NASA JPL, and Particle Metrics, Inc. for instrument teams;
  - MIT for Theory Team support; and
  - CIRES for Education and Public Outreach.
- The Project PI, Project Co-PI, and Project Coordinator will participate in the oversight of the subcontracts;
- Each subcontract will be defined with a Statement of Work;
- Subcontracts to non-government agencies will be monitored during the contract performance period by members of the MASC contracting unit and the Project PI and Co-PI.

The USAF, as the Global Hawk provider, has an existing subcontract with NG-RAC as the Global Hawk manufacturer and operator. No other contractual or financial relationships exist among the GHATTEX participating institutions. The relationship with the flight range will be handled by the existing arrangement between ASC/RAV and EAFB.

The subcontract to support the NG-RAC SOW will be handled by a transfer of funds from NOAA/AL to the USAF WPAFB. The relationship between USAF WPAFB and NOAA/AL regarding the transfer of funds for GHATTEX activities will be defined with an MOA (see **IP-Appendix J**). Both parties will sign the MOA before receipt of GHATTEX funds by NOAA/AL. WPAFB will transfer GHATTEX funds to NG-RAC based on the NG-RAC cost proposal and SOW (see **IP-Appendi**x **N)** and provide management of those funds during GHATTEX. As per 1st Lt Adam Wehner, the management approach for the NG-RAC SOW at WPAFB will include:

- Program Management
- Cost and Schedule Reporting
- Integrated project schedule

- Program reviews

The GHATTEX management team will make use of the management and reporting functions at WPAFB to monitor GHATTEX progress concerning cost and schedule issues.

The transfer of funds to USAF from NOAA/AL will be done under the U.S. Economy Act that facilitates interagency funding transfers. The NOAA/AL MOA with USAF will specify details of this transfer (see **IP-Appendix J**). This method was used successfully in November 2000 to transfer funds to NG-RAC for production of the GHATTEX Implementation Plan.

6.0.7 Workforce Staffing Plan

The GHATTEX workforce is distributed throughout several organizations and institutions (see **Table 3.2-1**). The work force staffing plan by WBS element and fiscal year is included in **Appendix E**. All participating teams that will receive GHATTEX funds have submitted budgets for their activities which are included in this proposal. These budgets include the costs of workforce staffing and, hence, indicate that sufficient staffing is available or will be acquired by each group to complete their respective GHATTEX tasks. The GHATTEX tasks to be undertaken by each group as outlined in the WBS are familiar to the respective group and, hence, each is highly experienced in planning the workforce staffing to accomplish the designated tasks. Thus, the risk to GHATTEX from workforce staffing issues is low.

7.0 Education and Public Outreach Plan

7.1. Project Overview

The GHATTEX UAV project is an engaging “hook” to promote learning about the processes of science, such as the interplay between scientific progress and technology. The goals of the mission, including testing for the presence of a “mirror-image” of the Walker cell in the lower stratosphere, and understanding more about global climate processes, provide a good opportunity for teaching fundamental concepts in scientific inquiry and Earth systems science. The project is well aligned with NASA’s strategic goals and objectives, particularly those of the ESE Education program. We will “educate the educators” through in-service and pre-service teacher education, develop and disseminate effective supplemental curriculum materials, inform new community audiences and the media, and involve scientists in science communication and education efforts.

Our specific goals include:

- to share the value of cutting-edge NASA-sponsored Earth systems research with a large, diverse, national audience;
- to increase public understanding of global climate and innovative UAV aeronautics;
- to increase public understanding of the relationship between science and technology; and
- to facilitate effective interaction between the science and education communities.

The well-established CIRES Outreach Program, University of Colorado, will have overall responsibility for providing GHATTEX EPO. Partnerships with Dryden Flight Research Center and Edwards Air Force Base Public Affairs Offices (PAOs), local schools, NASA’s national information dissemination infrastructure and others will provide a variety of informal and formal science education opportunities. We estimate that ~150 teachers, 1000 students, and more than 500 members of the general public could be reached by this program through direct contacts, teachers’ workshops, and the proposed Open House. A much wider audience will be reached via the proposed web site and public media (TV/radio).

7.2 Education and Public Outreach Statement of Work

Elements of the GHATTEX EPO project include formal education, informal education and media relations, diversity impacts, and leverage of existing systemic reform efforts. Front-end, formative and summative evaluation is included throughout the project, enhancing the usefulness of this project as a model for future Global Hawk and UAV EPO providers.

7.2.1 Formal Education

The GHATTEX project provides plenty of interest for students through the exciting aeronautics and cutting-edge scientific questions. That interest will in turn motivate cognitive learning gains. GHATTEX teacher-partners will be responsible for developing curriculum materials, which reflect inquiry-based best practices and are aligned with National Science Education Standards, and Colorado state and local district standards. An example of a standards-aligned activity would be to generate an experimental design to answer a specific climate question with a choice of UAV and other platforms and instrumentation. Students could then compare their solutions, discuss the trade-offs involved, and critique real study designs. In order to do this, students would need to understand how scientists know about global climate, the range and extent over which different processes occur, and the capabilities and uses of available technology, including UAVs and the Global Hawk. This activity would meet standards in inquiry, Earth and space science and technology. Other possible activities could include students gathering local data, such as sampling and analyzing local aerosol sources or observing weather patterns, then scaling up their understanding of local processes to the global scale addressed in GHATTEX objectives.

Teacher/Scientist partnerships: Teacher/scientist partnerships are the backbone of the project. Through these partnerships, the educational expertise of the teachers will be used to develop, test and disseminate GHATTEX educational materials, with contributions by GHATTEX scientists and outreach staff. GHATTEX Outreach personnel understand the important components of facilitating such partnerships, as demonstrated through our workshops (http:/cires.colorado.edu/`k12/earthworks) and our successful brokering of partnerships for the Teachers Experiencing the Arctic (TEA) Program (The field journal of a CIRES-brokered TEA teacher, Ms. Cathi Koehler, is online at http://glacier.rice.edu/tea/). In particular, we pay attention to strong facilitation of the partnership, explicit communication with all parties, and good organization (“Science Education Partnerships,” A. Sussman, Ed., University of California, San Francisco, 1993).

We will recruit two teachers for partnership with GHATTEX scientists. The teachers will be chosen by the following criteria:

- Grade level: one who teaches at grades 5 through 8 level and one who teaches at grades 9 through12 level.
- Experience: one mid- to late-career master teacher and a promising early career teacher.
- Proximity: the teachers should live close enough to NOAA to participate.
- Expertise: demonstrated ability in inquiry- and field-based classroom implementation.
- Diversity: we will pay special attention to recruiting excellent teachers who serve under-represented or disadvantaged groups.

In this way, we will mitigate the risk to the project from teacher attrition, provide a peer community and establish a mentoring relationship between the two educators

Teachers will be provided with stipends, substitute teacher costs, materials costs, and travel funds. Teachers will work with GHATTEX scientists for one day a month in the pre-deployment period, travel to Edwards AFB for both flight deployment periods, and spend six weeks in implementation and dissemination to other teachers (in-service and NSTA). Teachers will pilot-test materials with their own students, and provide access for evaluating the project. Scientists will aid in ensuring scientific accuracy and access to data for curriculum development, and will visit the teacher’s classrooms with hands-on interactive presentations.

Supplemental Curriculum Materials: GHATTEX-related curriculum products include:

- Educational component of the project web site.
- Mission posters with standards-aligned activities.
- Preparation of GHATTEX curriculum teacher guide and Scout badge materials.

Each supplemental educational product will be developed in adherence to NASA ESE Product review criteria, and will go through NASA ESE product review. We will disseminate the materials electronically, through teacher workshops (local, NSTA, Dryden FRC), to prospective teachers, and through our systemic reform venues.

For the education component on the project web site, the teachers will guide the development of the web site, establish appropriate content and activities, and pilot-test the prototype web site in their classrooms. This component will be implemented and maintained by Ms. S. Hovde, the CIRES GHATTEX scientist responsible for the overall project web site. The web site will contain the following elements:

- Teacher-designed investigations using a subset of GHATTEX data. A suitable student interface will allow data manipulation and exploration.
- Curriculum guide to web site and other GHATTEX curriculum materials.
- Photos and the teachers' field journals.
- Links to other sites of interest, such as NASA climate resources and UAV information.
- Press materials such as broadcast quality video and still photos of the GHATTEX mission with the Global Hawk, provided by the Dryden FRC public affairs office.
- Dissemination through other web sites and publications, such as the National Science Teachers Association web site and the NASA ESE newsletter.

For the mission posters, teachers will design a supplemental educational poster to be put through NASA ESE product review. A possible poster topic would be the types and uses of UAVs, with strong connections to mission and learning objectives. The poster will include activities on the bottom as a cut-off supplement and which will be available in portable document format on the project web site.

For the curriculum and teacher guides, the teachers will develop curriculum and teacher guides connected with the GHATTEX web site and the mission poster. These materials will also be disseminated and included in portable document format on the GHATTEX web site.

7.2.2 Informal Education and Media Relations

An Open House will be held at Edwards Air Force Base immediately following the winter deployment period. Public affairs personnel at Edwards AFB and Dryden FRC are very experienced at providing Open House events of this type, and have agreed to provide logistics, advertising and materials support.

Elements of the Open House include:

- advertising to school groups, aeronautics groups, Girl and Boy Scout groups, and senior groups;
- tours of the Global Hawk and hands-on presentations by the scientists;
- demonstrations of remote-controlled model aircraft by enthusiasts;
- teacher workshop with classroom materials in advance of the event;
- development of local Scout badge materials in aeronautics and/or climate to be disseminated beforehand and during the event;
- press releases and materials prepared by NOAA outreach personnel and the Dryden FRC public affairs office and distributed nationally; and
- estimated 500-plus attendees.

Press releases will be prepared and distributed several times during the project, prior to each deployment and to the Open House. NOAA personnel and the Dryden PAO will prepare the releases, press materials and disseminate them.

7.2.3 Diversity Impacts: Post-Secondary

In addition to using diversity as criteria in selecting GHATTEX teacher partners, we will make involvement in GHATTEX available to a participant in each of two diversity programs:

- The SOARS Program (Student Opportunities in Atmospheric and Related Sciences) is an effective program designed to retain talented minority-group undergraduates in geosciences. Information on the SOARS program may be found at http://www.ucar.edu/soars/. CIRES currently provides $*** per year to sponsor a SOARS protégé position, and travel funds have been included in the EPO budget to enable the protégé to take part in deployment flights at EAFB.
- NOAA's Boulder Environmental Technology Lab (ETL) partnership program with three Historically Black Colleges and Universities (HBUC) (Spelman, Clarke-Atlanta, and Morehouse), which bring faculty to Boulder for summer programs.

7.2.4 Leverage of Existing Efforts

Pre-service teacher education: The GHATTEX EPO coordinator is instructor of a NASA Opportunities for Visionary Academics (NOVA) course for pre-service teachers at the University of Colorado, Boulder (GEOL 2110 Physical Science in Earth Systems). The course is highly recommended for all University of Colorado, Boulder elementary certificate students, about 100 students per year. Our target impact over the project period is 2 to 3 sections per year with 25 students each. GHATTEX curriculum products will be included in the course, with the possibility of securing Phase III NOVA funding to develop and disseminate an on-line module for the other 76 NOVA institutions.

District systemic reform: GHATTEX curriculum products will be included in a resource book, which CIRES has developed for a local school district to support their Earth systems curriculum implementation. This effort is being disseminated as a model for similar implementation efforts.

7.2.5 Project Evaluation

An evaluation doctoral student in the School of Education will conduct formative and summative evaluation, a model that has been successful in the CIRES Outreach program. We are dedicating 7% of the total direct costs of the project to evaluation, with administrative and project coordinator time also available. This is in line with NSF evaluation guidelines (5 to 10%). In particular, we will evaluate the utility of the teacher/scientist partnerships from the perspective of all participants, the effectiveness of the curriculum materials, and the extent of increased public awareness due to the Open House. We intend the results of this evaluation to provide decision-making information for future providers of Global Hawk and UAV EPO. To this end, results of the evaluation will be included on the project web site.

Both qualitative and quantitative evaluation methods will be used to provide in-depth data and a basis of comparison between methods. Methods will include semi-structured interviews, participant journals, surveys, participant and student observation, and pre- and post-assessment of student learning. Prior to the start of the project, interviews will be conducted with all stakeholders (teachers, scientists, outreach staff) in order to assess the important objectives of all parties. The evaluation design particulars (such as interview questions) will be driven initially by education research on scientist/teacher partnerships and scientists involvement in outreach. However, we will remain open to unanticipated outcomes as we respond to the formative evaluation results.

Table 7.2-1 describes which assessment methods are connected to which project objective. Also included is a description of which participant groups are included and when during the project the assessment will occur. Each project element to be evaluated (partnerships, materials, and open house) is followed by a set of objectives for that element (i.e., the measurable goals for that element). For example, in order to assess the impact of the partnership on the GHATTEX teachers' practices, we will use interviews with the teachers, the teachers' journals, a survey instrument on teaching practices and observation in the teachers' classrooms as a basis for evaluation.

7.3 Education and Public Outreach Personnel and Qualifications

Dr. Susan Buhr (CIRES Outreach program Associate Director) will have overall responsibility for implementing the GHATTEX EPO project. Dr. Buhr is an educator and scientist able to carry out these responsibilities, as described in her CV. Other CIRES outreach staff expertise in traditional and on-line curriculum development, evaluation, and classroom teaching will also be available.

Ms. Jenny Baer-Riedhart (Dryden FRC) will provide advertising, logistics, and press materials support for the Open House.

Mr. Gary Martins (Edwards AFB) will provide support for the Open House.

Dr. Christine Ennis (Aeronomy Laboratory) will provide a point of contact with the NOAA public affairs office.

Ms. Susan Hovde (CIRES/AL) will provide technology expertise for the project web site, and will implement the EPO web site. See her CV in the personnel section.

Table 7.2-1. Education and Public Outreach Project Evaluation

Project Element and Associated Objectives	Methods Used to Assess Objective			
Element 1. Teacher/Scientist partnerships	Interview pre-,mid-, and post partnership	Teacher Journals	Survey inventory of teaching practices	Observation: students and partners in action
Objective 1a. Assess effectiveness of partnership from all participants' perspectives.	Teachers, scientists and staff	Qualitative analysis of themes	---	At NOAA, in field and in classroom
Objective 1b. Assess impact on teachers' practices.	Teachers	Qualitative analysis of themes	Pre- and post-	Classroom
Objective 1c. Increase understanding of factors important in scientist education outreach.	Scientists	---	---	---
Element 2. Curriculum materials	Interviews	Surveys	Observation	Other methods
Objective 2a. Assess usability of web site by students during classroom pilot-test	Teachers/ Students	---	Teachers/ Students	Student talk-aloud
Objective 2b. Assess utility to teachers of web site/poster/curriculum guide.	Workshop attendees	Workshop attendees, web site visitors	Workshop attendees	Site counters, trackers
Objective 2c. Assess student learning gains	Teachers-GHATTEX and workshop attendees	GHATTEX Teachers and workshop attendees	Class visits	Pre- and post-assessment
Element 3. GHATTEX Open House	Interviews	Surveys	Short-answer survey	
Objective 3a. Increase public awareness of Earth Systems phenomenon	Attendee exit interviews	Attendee exit surveys	Feedback from Scout and community group leaders	
Objective 3b. Increase public awareness of NASA's enabling role	Attendee exit interviews	Attendee exit surveys	Feedback from Scout and community group leaders	

7.4 Education and Public Outreach Costs

GHATTEX EPO direct costs are approximately 1% of the project total, plus University of Colorado indirect costs. CIRES will contribute two months of Dr. Susan Buhr's salary to the project, and will contribute $*** per year to the National Center for Atmospheric Research to support a SOARS protégé.

7.5 Education and Public Outreach Work Schedule

A schedule for EPO activities is shown in **Figure 7.5-1**. See the detailed evaluation plan for the evaluation work schedule.

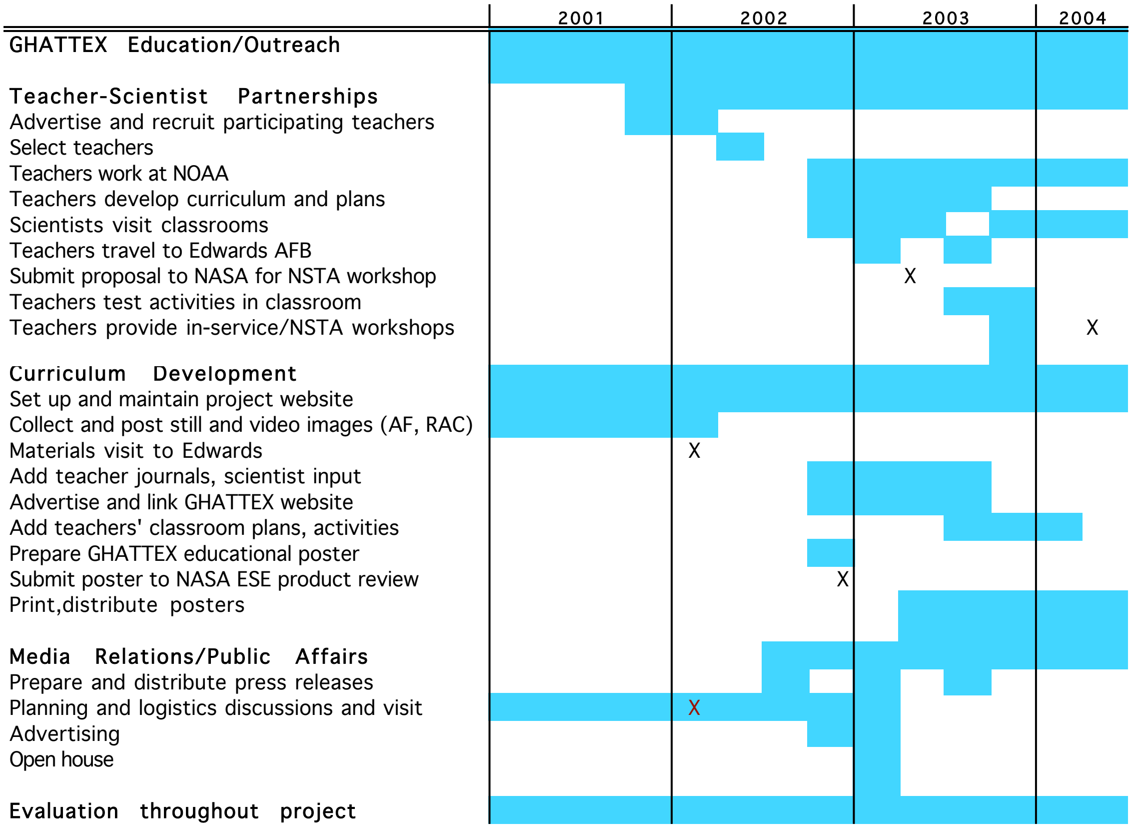

Figure 7.5-1. Education and Public Outreach Activity Schedule

Appendix A: Acronyms

Acronym	**Definition**
AAOE	Airborne Antarctic Ozone Experiment
AASE	Airborne Arctic Stratospheric Expedition
AASE II	Airborne Arctic Stratospheric Expedition II
ACCENT	Atmospheric Chemistry of Combustion Emissions Near the Troposphere
ACMAP	Atmospheric Chemistry Modeling and Analysis Program
AEAP	Atmospheric Effects of Aviation Project
AFB	Air Force Base
AFFTC	Air Force Flight Test Center
AFMC	Air Force Materiel Command
AFMSS	Air Force Mission Support System
AL	Aeronomy Laboratory
APMP	Airborne Payload Mounting Plate
ASC/RAV	Aeronautical Systems Center/ Reconnaissance Systems Program Office
ASHOE/MAESA	Airborne Southern Hemisphere Ozone Experiment/Measurements for Assessing the Effects of Stratospheric Aircraft
ATC	Air Traffic Control
CIRA	Cooperative Institute for Research in the Atmosphere
CIRES	Cooperative Institute for Research in Environmental Sciences
CCO	Command and Control Operator
CFR	Code of Federal Regulations
COA	Certificate of Authorization
DRR	Deployment Readiness Review
EAFB	Edwards Air Force Base, CA
EMI	Electromagnetic Interference
EPO	Education and Public Outreach
ERL	Environmental Research Laboratories
ESE	Earth Science Enterprise
ETL	Environmental Technology Laboratory
EVS	Earned Value System
FAA	Federal Aviation Administration
FCAS	Focused Cavity Aerosol Spectrometer
FFS	Fiberglass Fairing Structure
FL	Flight Level
FLTS	Flight Test Squadron
FRR	Flight Readiness Review
GCM	General Circulation Model
GHATTEX	Global Hawk Tropical Tropopause Experiment
GMS	Geostationary Meteorological Satellite
GOES	Geostationary Operational Environmental Satellite
GPCC	GHATTEX Payload Control Computer
GPS	Global Positioning System
HAE	High Altitude Endurance

HBUC	Historically Black Universities and Colleges
ICD	Interface Control Document
ID	Identifier
IMMC	Integrated Mission Management Computer
INMARSAT	International Maritime Satellite
IPM	Integrated Project Management
ITCZ	Inter Tropical Convergence Zone
JPL	Jet Propulsion Laboratory
MASC	Mountain Administrative Support Center
MASP	Multiple-Angle Aerosol Spectrometer Probe
MFTL	Mean Flight to Loss
MIT	Massachusetts Institute of Technology
MM5	NCAR/PSU Mesoscale Model 5
MOA	Memorandum of Agreement
MTP	Microwave Temperature Profiler
MTTCF	Mean Time to Critical Failure
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NG-RAC	Northrop Grumman, Ryan Aeronautical Center
NMASS	Nucleation-Mode Aerosol Size Spectrometer
NOAA	National Oceanic and Atmospheric Administration
NOVA	NASA Opportunities for Visionary Academics
NRA	NASA Research Announcement
NSF	National Science Foundation
OES	Office of Earth Science
OLR	Outgoing Longwave Radiation
PALMS	Particle Analysis by Laser Mass Spectrometry
PAO	Public Affairs Office
PDF	Probability Distribution Function
PI	Principal Investigator
PIC	Pilot-In-Command
POES	Polar-Orbiting Operational Environmental Satellite
POLARIS	Photochemistry of Ozone Loss in the Arctic Region In Summer
PP	Project Plan
PSU	Pennsylvania State University
PT	Pressure-Temperature Instrument
QBO	Quasi-Biennial Oscillation
RCC	Range Commanders Council
ROA	Remotely Operated Aircraft
SAR	Synthetic Aperture Radar
SATCOM	Satellite Communication
SOLVE	SAGE III Ozone Loss and Validation Experiment
SOW	Statement of Work

SPADE	Stratospheric Photochemistry Aerosols and Dynamics Experiment
SRB	Safety Review Board
STEP	Stratosphere-Troposphere Exchange Project
STRAT	Stratospheric Tracers of Atmospheric Transport
SWPA	Short Work Package Agreement
THA	Test Hazard Analysis
TRA	Teledyne Ryan Aeronautical
UARP	Upper Atmosphere Research Program
UARS	Upper Atmosphere Research Satellite
UAV	Uninhabited Aerial Vehicle
USAF	United States Air Force
UT/LS	Upper Troposphere/Lower Stratosphere
WAM	WB-57F Aerosol Mission
WBS	Work Breakdown Structure
WPAFB	Wright Patterson Air Force Base

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