# Global Albedo Project (GAP)

Dear Dr:

**<u>Subject</u>:** ***How do Aerosols and Clouds Regulate the Global Albedo?***

We are writing this letter to explore the interest of your agency in addressing a fundamental question in climate dynamics which has to be attacked from an observational perspective: How do Aerosols and Clouds regulate the planetary albedo?

The global average planetary albedo is about 30% (±2%). The albedo of the clear sky region of the planet is about 15% (±2%). Thus the presence of clouds enhances the albedo of a cloud free earth by about a factor of two, from 15% to 30%. We also know that, while the atmospheric circulation determines the location and extent of clouds and water content, aerosols determine the size and number distribution of cloud drops and ice crystals. The aerosol properties are determined by the chemistry (e.g. oxidation of sulfur dioxide) and the biology (dimethyl sulfide and organics). All of these parameters including the aerosol concentration and composition undergo significant temporal (minutes to years) and spatial (meters to planetary scales) variations. Yet it is remarkable that our general circulation climate models are able to explain the observed temperature variations during the last century solely through variations in greenhouse gases, volcanoes and solar constant. This implies that the planetary albedo has not changed during the last 100 years by more than ±0.2% (out of 30%).

On a more fundamental level, the GAIA hypothesis involves black daisies (greenhouse gases) and white daisies (aerosols and clouds) as the means by which the biota regulates an optimum climate. A fundamental question, we as a community have to address is: Why is the global albedo about 30%? To understand why this is an important question, consider the following two examples. A global albedo of 33% would plunge the Earth into a climate similar to that of the last ice-age; while an albedo of 27% would be comparable to a five-fold increase in the $CO_2$ concentration. It is also a well known fact that there is practically no theory for explaining how the cloudy sky albedos are regulated. Given this state of the field, and given the fact that clouds exert a large global cooling effect (about –15 to 20 $Wm^{-2}$ globally; see Figure 1 for the regional distribution of this cooling effect) we need a new approach to cut through the current impasse on this fundamental problem in climate dynamics.

On a more practical level, the link between aerosols and cloud albedo produces the so-called indirect effect of anthropogenic aerosols. Many models and some field observations (e.g, INDOEX and ACE-II) have shown that an increase in anthropogenic aerosols can nucleate more cloud drops (see Fig. 2) and enhance the cloud albedo and lead to a cooling effect. The IPCC-2001 report shows that this cooling effect may be large enough to offset 50% to 100% of the radiative heating due to the build up in greenhouse gases. This indirect effect (i.e, the regulation of cloud albedo by anthropogenic aerosols) is acknowledged to be the largest source of uncertainty in understanding the human impact on the global climate.

It is clear to us that new discoveries await us in a serious quest that determines, from observations, the processes by which aerosols regulate cloudy sky albedo. For reasons given below, the unmanned platform is the only practical means for addressing this fundamental question in climate dynamics: a) *The link between aerosol and clouds can only be determined with in-situ data*; b) Given the large variability of aerosol and cloud properties, we need to collect adequate samples of data under a variety of meteorological conditions and under a range of aerosol concentrations ranging from pristine to highly polluted conditions. *The available data are taken mainly from field campaigns with a typical duration of 4 to 6 weeks involving less than 100 total flight hours and hence the field of cloud physics is severely sample limited. Given the cost and manpower requirement, it is prohibitive to collect the needed data with conventional piloted aircraft*.

We are proposing the GAP Drone (Fig. 3) and flight program (Fig. 4) to solve the aerosol-cloud-planetary albedo problem. It consists of the following:

Remotely piloted aircraft (Drone) with a maximum range of about 7000 km, and a payload of about 15 kgs (see Fig. 3 which is based on a provisional analysis of the envisioned platform by Dr. Paul MacCready of AeroVironment, Inc.). No platform with this range and payload capability seems to exist at this time.

A set of aerosol, cloud physics and radiation instruments with the aircraft (see Fig. 5).

Three aircraft in formation flying, with one above the cloud top to measure aerosol concentration (condensation particle counter) and cloud albedo; one below the cloud base to measure aerosol concentration, cloud condensation nuclei and transmitted solar radiation; and one through the cloud to measure aerosol concentration, cloud water content and drop size distribution.

The Pacific Ocean between equator and 45$^o$N is chosen as our natural experimental area. It contains cloud systems with the largest radiative cooling effect (See Fig. 1). It contains a range of aerosol conditions with highly polluted airmasses from Asia and northern California (see Fig. 6) and it also contains pristine marine airmasses. Depending on the weather conditions and available cloud systems, we will fly one- way trips routinely from La Jolla to Hawaii, or out and return trips anywhere within the range from La Jolla or from Hawaii (see circled domains in Fig. 7) to sample a variety of strato cumulus, trade cumulus and shallow to moderately deep (tops around 4 kilometers) cumulus clouds under pristine (low aerosols) and polluted conditions (high aerosol loading). One of the important objectives of the flights from Hawaii would be to sample the clouds subject to Asian aerosols.

We will carry out about one round trip flight mission every 10 days for an entire year, collecting about forty, 5000 km samples in one year. The aircraft data will be collocated with TERRA and AQUA satellites. The data for aerosols, cloud and radiation budget from these satellites will be used to extrapolate the aircraft results to larger regional scale cloud systems in the Pacific Ocean. Based on the success of these missions, we will propose to undertake similar missions in other oceanic regions.

We will adopt the following conservative path to the operational flight goals of three aircraft. Step 1 (first 9 months): Single aircraft with aerosol and cloud physics instruments and limited flying around California coast. Step 2 (next 3 months): Single aircraft flight from California to Hawaii. Step 3 (next 12 months): Two aircraft configuration (cloud base and in-cloud) flying below 5500 ft, the currently allowed ceiling by FAA; and then maturing to the 3 aircraft configuration. We will also have to develop jointly with the FAA operational procedures with respect to controlled airspace. This effort will pioneer a new way of observing clouds and finally solve the problem of the statistical robustness of cloud physics data, which in turn, will lead to a sound theory of how the planet's climate is regulated by aerosols and clouds.

We hope the proposed new approach will interest your agency and that you will give us the opportunity to make a more formal proposal. If invited, we are prepared to submit to you a cost and schedule estimate for the aircraft, instruments and flight operations. It is our expectation that if approved by 2002, the first research flight with single aircraft will occur by end of 2003.

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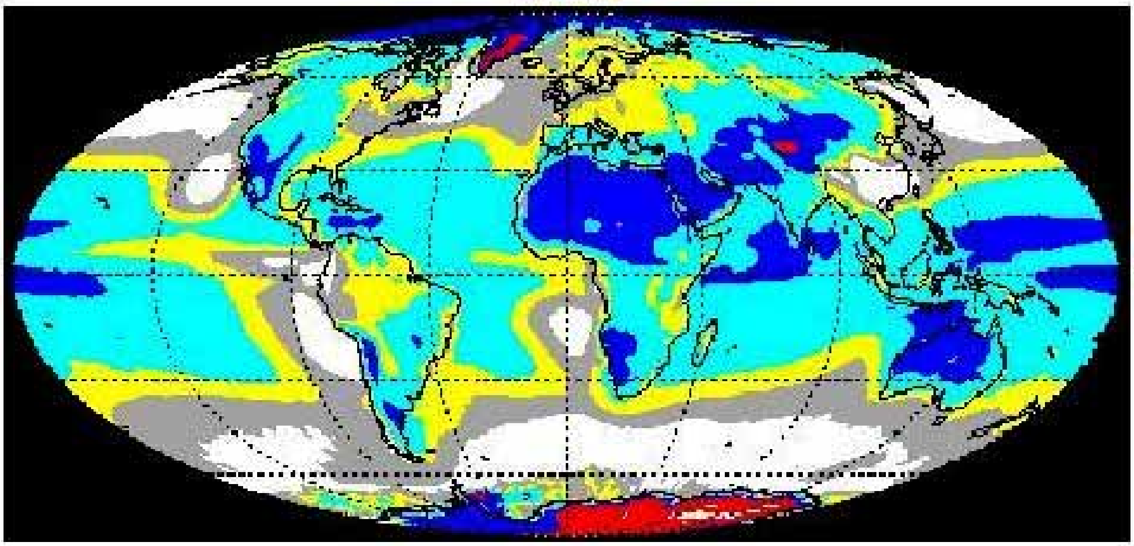
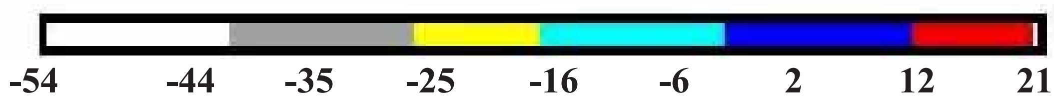
## Fig. 1. Observed (ERBE) Net Cloud Forcing [W $m^{-2}$], 1985-1989

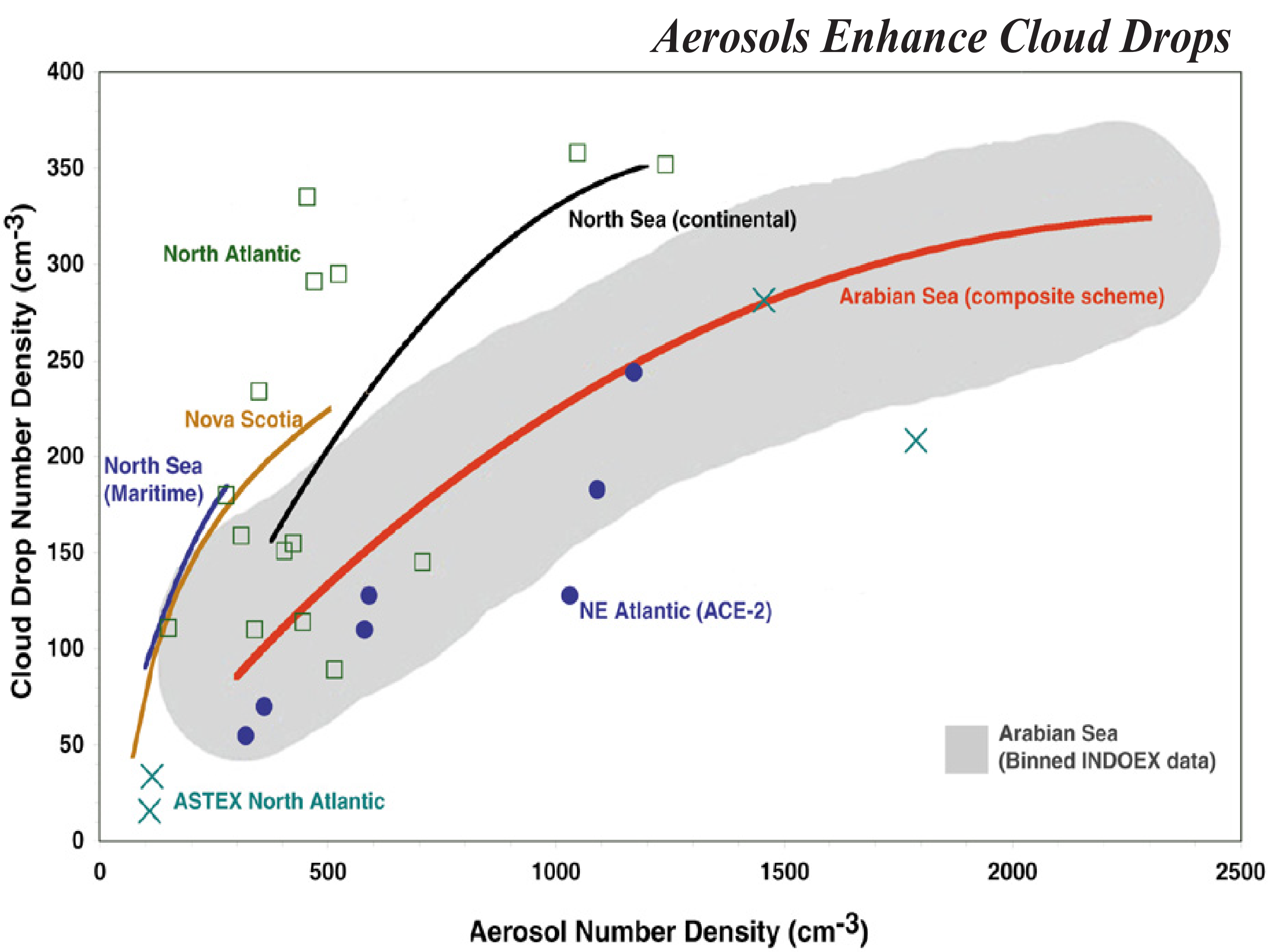
*Source: Ramanathan et al, 1989; 1994; Harrison et al, 1991*





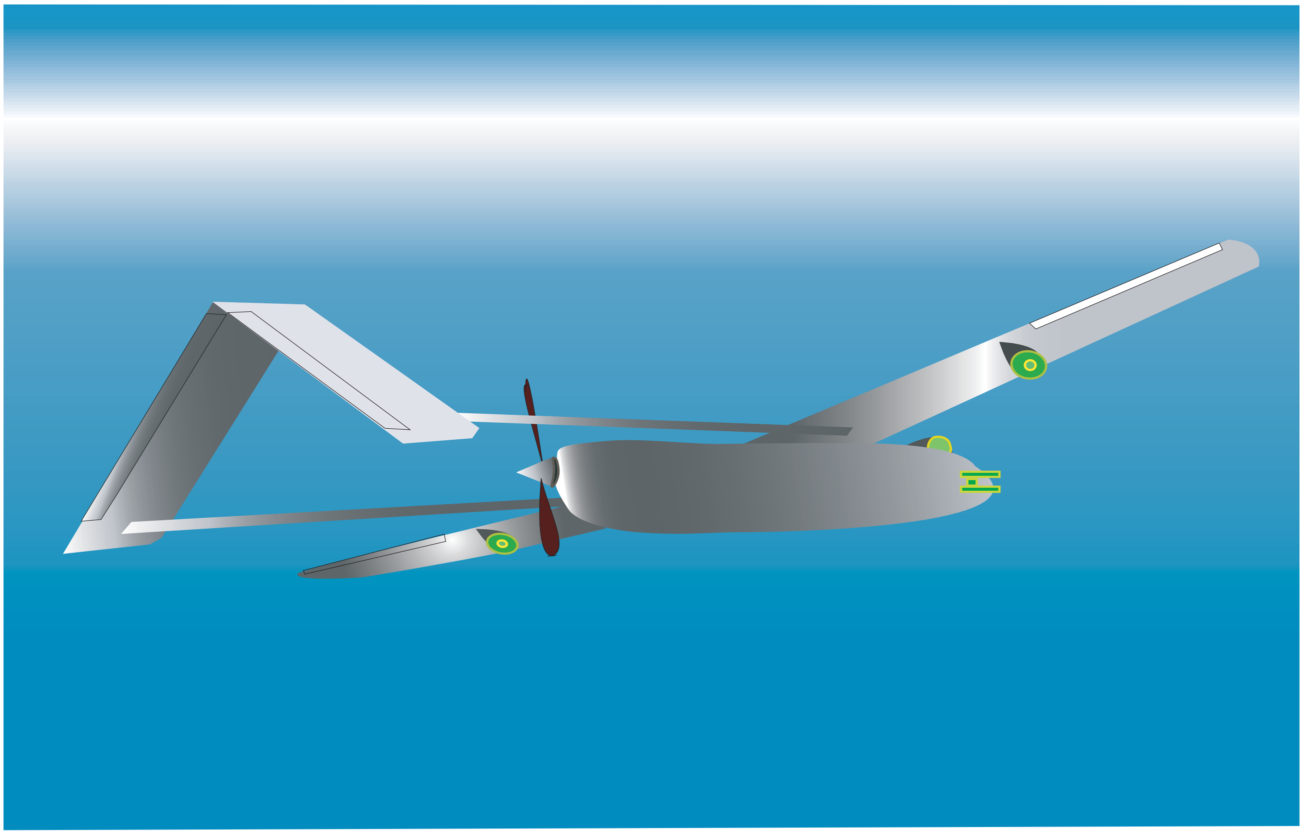

The net cloud forcing is the effect of clouds on the radiation budget at the top-of-the atmosphere.

# Fig. 2. In-situ Measurements of Aerosols and Clouds




Ref: Ramanathan, Crutzen, Kiehl and Rosenfeld, *Science* 2001.

# Fig. 3. GAP Drone



*Three-dimensional rendition based on sketches by P. MacCready, AeroVironment, Inc.*

**Take-off aircraft weight: under 65 kg**
**Wing span: 5 - 6 m**
**Flight speed: 90 - 130 km/hr**
**Payload weight: 15 kg**
**Engine: 3 - 4.5 hp (peak power)**
**Maximum range: 7,000 km**
**Maximum flight duration: 70 hrs**
**Flight duration from southern California to Hawaii**
**(distance of 4,200 km): approximately 40-60 hrs (depending on the winds)**

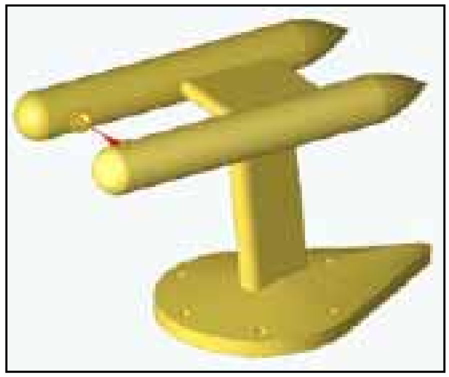
Fig. 4.  Global Albedo Project (GAP) Drone System

# Fig. 5. GAP Instruments
**(will be tailored to the aircraft)**

### Condensation Particle Counter

1.7 kg; 20 W
Particle size range: 0.01 - >1.0 µm
Concentration range: 0 - 100,000 particles cm-3

### Cloud Droplet Spectrometer



5 kg, 50W

### Cloud Condensation Nuclei (CCN) Counter

Continuous-Flow Thermal-Gradient CCN Counter
Supersaturation (0.2 - 2%)
<5 kg, ca. 50 - 75 W

### Radiometers

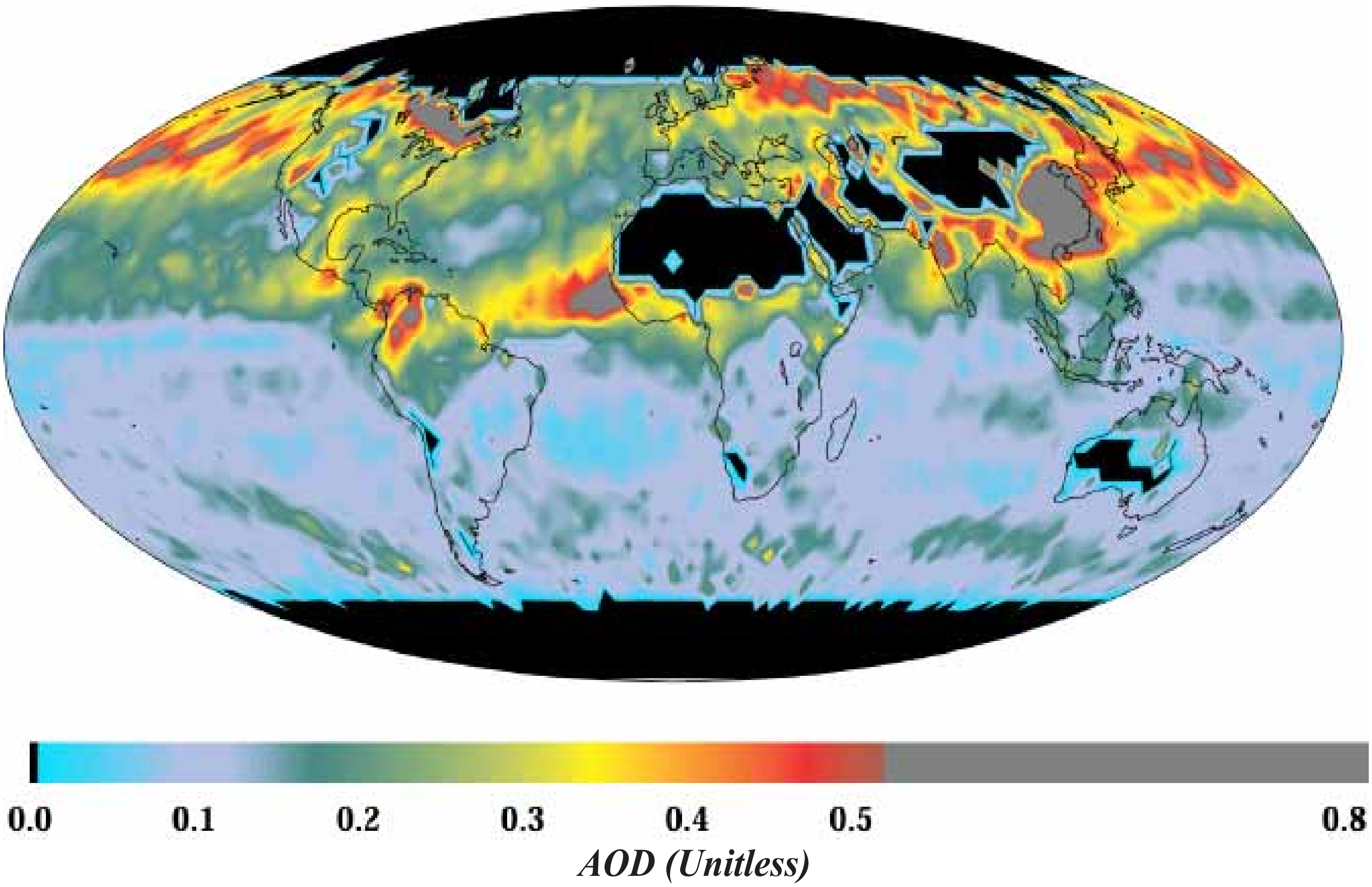
Kipp & Zonen Broadband Pyranometer
0.8 kg*, <1 W

Kipp & Zonen Narrowband Pyranometer
0.8 kg*, <1 W

*Weights are for instruments only (weights of cables, datalogger, etc. not included).

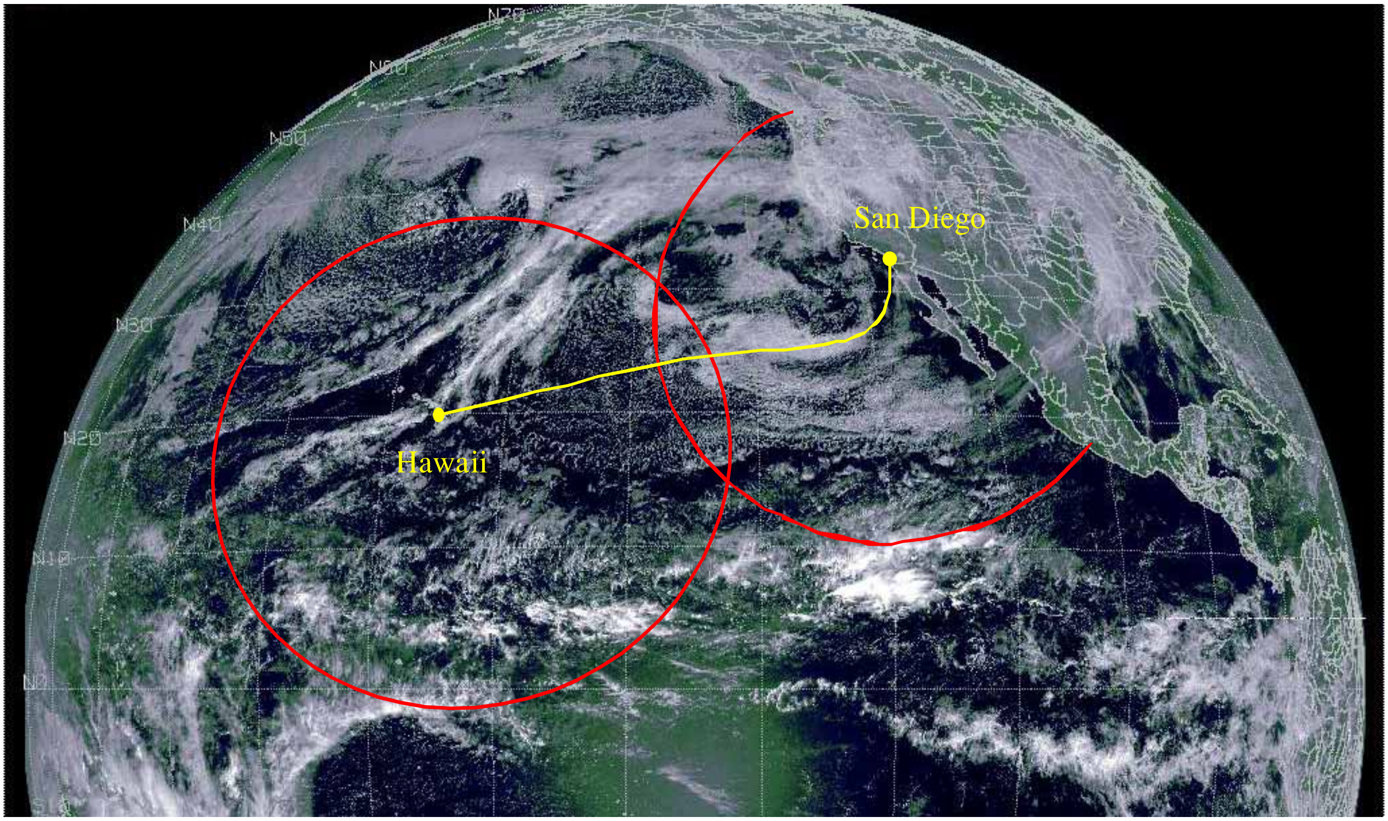
# Fig. 6. Aerosol Optical Depth: April 2001
## NASA-TERRA Satellite; MODIS Instrument

***Shows Long Range transport of aerosols from Asia to the West coast***




***Courtesy of Y. Kaufman, NASA-GSFC.***

# Fig. 7. Flight Range of GAP




GOES-10 2002-02-19 21:00 UTC Visible

The yellow line shows an example of a flight path to study cloud systems that extend off the coast of the North American continent. The red circles indicate a 2250 km radius from San Diego and Hawaii to illustrate the range of the RPV for an out-and-back flight.