Comparison With Clementine Laser Altimeter Data

To verify the elevations in the terrain models, the scientists selected laser altimeter data from Clementine orbits 270 and 272 and extracted heights from the stereo-image-derived DTM at the laser return points. The elevations from the two data sets agreed very well (Figure 3). The systematic offset in absolute height of approximately 300 m results from small remaining uncertainties in the camera pointing during the block adjustment. The scatter between the two is due to the mismatch between the large Galileo image pixels, the matching patches, and the small laser altimeter footprint size of approximately 200 m. This comparison suggests that the laser altimeter data may be used to define absolute elevations, whereas the stereo image data can provide higher resolution terrain information between the sparsely distributed laser return points.

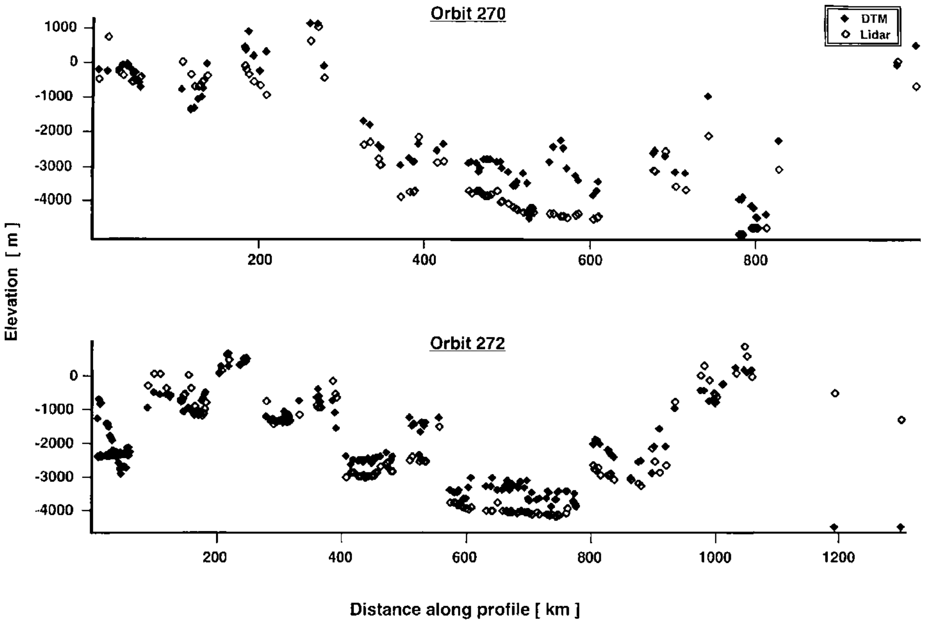

Fig. 3. Comparison of the elevation data extracted from the stereo terrain model (Figure 2) with elevations from Clementine laser altimetry along the profiles shown in Figure 2. The spacecraft moved from south to north. Note the excellent correlation between the two data sets.

Future Prospects

The availability of CCD cameras and advances in photogrammetric processing of digital images have greatly improved our ability to obtain high-resolution topography of the lunar surface. The new data may help lunar scientists identify impact basins on the Moon and map their rings and ejecta blankets. The data could also elucidate the dynamics of impact events, as well as the processes that followed their formation, such as viscous relaxation, rebound, or lava emplacement. With the availability of terrain information, scientists can determine solar incidence and emission angles more precisely with respect to surface slopes and apply accurate photometric corrections to images and, hence, carry out reliable compositional interpretations.

These studies suggest that stereo imaging should be firmly included in the planning of future deep space missions. The viewing and illumination conditions of imaging sequences must be planned very carefully; otherwise, features become difficult to recognize, and the automated stereo analysis techniques will fail. Cameras featuring large pixel arrays should be selected, as they improve the stability of the terrain models and reduce processing time and costs. Operating dedicated stereo cameras for near-simultaneous multi-look imaging is even more desirable.

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Intercomparison Makes for a Better Climate Model

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Global coupled climate models are elaborate numerical/physical formulations of the atmosphere, ocean, cryosphere, and land which are "coupled" together and interact to simulate the three-dimensional distribution of the climate over the globe. Such models are used to make projections of future climate change due to human activity. Simulation results are widely used to identify vulnerabilities and to study societal impacts that have policy implications. It is clearly important for the scientific community to systematically assess the simulation capabilities of these models.

The climate modeling community is doing so in the Coupled Model Intercomparison Project (CMIP) which is an assessment of the "state-of-the-art" in global coupled climate modeling. This activity is being organized by the World Climate Research Programme under the auspices of the Climate Variability and Predictability (CLIVAR) project.

The objectives of the first phase of CMIP (CMIP1, which began in 1996) are to document systematic simulation errors of global coupled climate models in the components of atmosphere, ocean, and cryosphere; quantify the effects of flux adjustment (additive correction terms applied to quantities exchanged between component models at the air-sea interface to maintain a state close to the observed) on coupled simulations of mean climate and climate variability; and

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document features of simulated climate system variability on a variety of time and space scales.

The second phase of CMIP, CMIP2, has just begun and will involve an intercomparison of global coupled model experiments with atmospheric CO_2 increasing at a rate of 1% per year compounded where CO_2 doubles at around year 70 of 80 total years. The goals of CMIP2 are to document the mean response of the dynamically coupled climate system to a transient increase of CO_2 in the models near the time of CO_2 doubling; quantify the effects of flux adjustment on climate sensitivity in the coupled climate simulations; and document features of the simulated time-evolving climate system response to gradually increasing CO_2. Diagnostic subprojects will focus on evaluating the coupled model simulations through analyses of processes, phenomena, and regional characteristics, and by comparison with the best observations available.

Such global coupled climate models represent our best attempt to simulate the Earth's climate system. These elaborate numerical/physical formulations of the atmosphere, ocean, sea ice, and land simulate the climate by calculating time varying solutions of the governing equations for atmosphere and ocean. The equations step forward in time for many years, allowing the models to project future climate change due to human activity.

Global coupled climate models are extremely computer-intensive. For example, to simulate 100 years of climate from a typical global coupled model takes around 1000 hours on a modern supercomputer. Although the models contain certain simulation errors, they nevertheless do a reasonable job of simulating first-order aspects of large-scale regional climate and variability. Such models are currently the primary tools used to investigate the problem of anthropogenic climate change. Since simulation results are widely used to identify vulnerabilities and study societal impacts that have policy implications, the simulation capabilities of these models must be systematically assessed. CMIP fills this role.

Data for the first phase of CMIP have been collected from 18 global coupled models from Australia, Canada, France, Japan, Germany, the United Kingdom, and the United States, representing virtually every group in the world with a current functioning global coupled climate model. Part of the motivation for CMIP is to systematically intercompare models whose results are used by the Intergovernmental Panel on Climate Change (IPCC), which organizes international assessments to provide policymakers with best estimates of possible future climate change due to human activity [e.g., *IPCC*, 1996].

Objectives of Intercomparison

The first objective of CMIP1, which began in 1996, is to document systematic simulation errors of global coupled climate models. This is done by comparing the mean model output to observations to determine how well the coupled models simulate current mean climate. Differences between model-simulated and observed quantities indicate systematic errors. Such errors show where and in what ways the models are succeeding or failing to reproduce the behavior of the atmosphere, ocean, sea ice, and land surface under current climate conditions. For example, a typical systematic error is warmer-than-observed sea surface temperatures off the west coasts of the subtropical continents [*Meehl*, 1995]. This error is usually associated with a poor simulation of the low-level stratocumulus clouds. A lack of sufficient cloud cover in these regions allows too much sunlight to reach the ocean surface. Sea surface temperatures then become warmer than the observed temperatures.

The atmosphere and the underlying ocean surface interact with each other through fluxes of heat, fresh water, and momentum. These fluxes are determined by net radiation, temperature of the overlying atmospheric surface layer, precipitation, evaporation from the surface, and the force of the wind acting on the ocean surface. The ocean, sea ice, and land surface then influence the atmosphere via surface temperature, soil moisture, snow, and sea ice distributions. When the model components are coupled together, errors in the fluxes and corresponding surface conditions result in errors in the coupled climate simulation of temperature, pressure, moisture, winds, ocean currents, and rainfall. A technique called flux adjustment (also referred to as flux correction) is sometimes used to overcome these simulation errors and bring the coupled climate simulation into better agreement with observations. About half the coupled models in CMIP1 use this technique.

Flux adjustments are designed to bring the coupled model simulation into closer agreement with observations. As such, there are constant additive terms, not interactive or restorative terms, which modify the fluxes between model components Therefore since terms are simply added and the model is not being restored to some observed state, the model is still free to drift away from present-day climate.

In the case of a lack of sufficient low-level clouds in the example mentioned above, the flux adjustment would be calculated to reduce the heat flux into the ocean. Thus the sea surface temperatures would be somewhat cooler and agree better with observations.

Once calculated, the flux adjustments remain constant in model simulations of present-day and future climate. Flux adjustment ensures that the physical climate feedbacks in the models are operating in the correct climatic range so that perturbations are appropriately modeled. For instance, "albedo feedback" is important for climate change. Warming of the surface melts snow and ice, thereby reducing the surface albedo. This leads to an enhanced absorption of incoming solar radiation that heats the surface, more snow and ice melt, and so on in a feedback loop (cooling drives the loop in the opposite sense). If the control climate simulated in the models has too much or too little snow and ice, the nature of the response to a climate perturbation will be affected.

Since the flux adjustment makes the coupled model simulation agree better with observations, most coupled models that use flux adjustment simulate present-day climate better than the models that do not. Nevertheless, the various component models used by different modeling groups tend to have similar systematic simulation errors before the flux adjustment technique is applied in the coupled simulations. If the feedbacks in a nonflux adjusted coupled model are affected (the albedo feedback, for instance), the climate simulated by an unflux-adjusted model could be compromised. Conversely, the magnitude of the flux adjustment—as in the case of too few low-level clouds in the simulation—is a measure of the mismatch between component models. Such inconsistencies could perhaps mask the lack of a missing physical feedback mechanism in the coupled system.

The second objective of CMIP1 is to assess possible effects of flux adjustment on coupled climate simulations. Of course, coupled modeling groups hope to eventually eliminate flux adjustment while retaining an acceptable simulation of current climate. CMIP will assist in this process by documenting climate simulation characteristics among models with and without flux adjustment.

The third objective of CMIP1 is to assess the ability of current coupled models to simulate the variability of surface air temperature. This will include seasonal-to-interannual temperature variations as well as over decades and longer timescales. This is important for understanding the processes and mechanisms involved in climate variations, for quantifying climate variability for applications in the detection of climate change in the observational record, and for projecting how variability might change as climate changes.

The model-simulated quantities, termed "fields," requested for CMIP1 elaborate on those used in a study by Boer and Lambert [*IPCC*, 1996]. The fields include the time mean geographical distributions of terms at the Earth's surface, which are indicative of the interaction between the components of the coupled system. These include, for example, surface wind, temperature, moisture, and fluxes of heat, momentum, and fresh water. Additionally, some time mean measures involving latitudinal and vertical structure of, for instance, temperature, winds, and currents will be collected. Time series of monthly mean surface air temperatures are also being requested to provide a general assessment of climate variability.

The objectives of CMIP2, which has just begun, follow those of CMIP1 but are applied to climate change experiments performed by the coupled models with CO_2 increasing at a rate of 1% per year compounded. Thus the sensitivity of the model climates to this anthropogenic forcing will be compared in terms of the mean climate change, the effects of flux adjustment on the simulated climate changes, and the time-evolving aspects of the simulated anthropogenic climate changes.

In formulating CMIP, the number of requested fields was constrained to a subset of all possible fields that are produced by the models. CMIP is a focused coupled model intercomparison with specific objectives, mentioned above, requiring a manageable level of effort from participating groups. A more extensive compilation of model output may be considered subsequently. Additionally, time series of some fields from limited portions of the coupled model integrations were collected as part of two separate coupled model intercomparisons that will focus on specific processes in the coupled models: The El Niño-Southern Oscillation Simulations in Coupled Models Project (ENSIP) and Study of Tropical Oceans in Coupled Models (STOIC).

CMIP1 Subprojects

While collecting coupled model data permits us to perform a basic intercomparison of model behavior, a broader data analysis can only be accomplished by involving the wider climate research community. Thus, proposals for Diagnostic Subprojects for CMIP1 are being sought by the CMIP Panel, though no direct funding is available from CMIP.

The panel will strive to ensure that all approved subprojects have scientific merit and a high probability of being completed and are coordinated appropriately with one another and with the modeling community. Diagnostic subprojects will focus on evaluating the coupled model simulations through analyses of processes, phenomena, and regional characteristics, and by comparison with the best observations available.

For a listing of the fields collected for CMIP1, details on how to initiate or participate in CMIP1 subprojects, and descriptions of required participation and collaboration protocols, please visit the CMIP1 subproject web site at http://www-pcmdi.llnl.gov/covey/cmip/diagsub.html.

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Aircraft Contrails Reduce Solar Irradiance

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A topic of considerable interest today is whether condensation trails generated by the growing number of passenger and other jet aircraft (Figure 1) alter Earth's radiation balance enough to influence regional weather and global climate [e.g., *Rind et al.*, 1996].

While any global influences of contrails have yet to be detected, a number of studies show possible regional effects. *Changnon* [1981], for example, suggested a possible link between contrails from jet aircraft and a reduction in the diurnal maximum and minimum temperature in the midwestern United States. Cirrus evolved from contrails has even been reported to reduce the warming of a solar-heated house [*Robinson*, 1996].

Recent studies emphasize measurements of the nature, composition, and evolution of the gases and aerosols that form contrails [*Hagen et al.*, 1996]. The accumulation of these combustion byproducts could have a long-term effect on Earth's radiation balance. Results of the most recent such study, NASA's SUCCESS project, were presented at the AGU Spring Meeting in Baltimore.

No significant impact on global climate was ascribed to contrails at the meeting. There were suggestions, however, of decades of localized effects from multiple occurrences of contrails.

It is widely accepted that contrail overcasts are likely to suppress nocturnal cooling rates similar to the abilities of cirrus. We are unaware, however, of any published study that associates the aerosol optical thickness (AOT) of contrails and contrail overcasts with localized temperature reductions during the daytime hours. Measured reductions in both direct-Sun and global solar irradiance may explain reductions in daytime temperature and diurnal temperature range (DTR) associated with localized contrail overcasts.

Figure 1 shows the AOT of a typical contrail over Fairbanks, Alaska, on August 20, 1996. The maximum increase in AOT over the background amount of the blue sky on either side of the contrail is 0.15 at 376 nm, 0.17 at 540 nm and 0.16 at 680 nm. These data are very similar to the mean AOT of thin cirrus clouds at solar noon in south Texas on 12 days in 1996. On these days the mean increase in AOT over the background AOT on the nearest days with a clear sky is 0.20 at 540 nm and 0.15 at 680 nm (376 nm not measured). Thus, the measured AOT of a contrail in a clear Alaska sky closely resembles that of thin cirrus in south Texas, where contrails are uncommon.

A single contrail drifting past the Sun has only a very brief effect on the AOT in the shadow zone. However, contrails that persist and spread in large groups can simulate natural cirrus overcasts and potentially have a significant impact on the surface temperature. During one particularly widespread occurrence of persisting contrails over the midwestern United States on April 17–18, 1987, average maximum surface temperatures near the center of the contrail region were 2–4°C cooler then in surrounding locations just outside the contrail region, analysis of National Weather Service data indicates (D. J. Travis, Diurnal Temperature Range Modifications Induced by Jet Contrails, unpublished manuscript, 1996).

Further comparisons of the 30-year normals of DTR for the United States prior to and immediately following the rapid increase in air traffic beginning in the early 1960s demonstrate a significant direct correlation between those regions estimated to have received the greatest amount of contrail coverage and those regions experiencing the greatest decrease in DTR [*Travis and Changnon*, 1997]. This may explain the unevenly distributed regional decreases in DTR in the United States reported by *Karl et al.* [1993]. Further analyses are required to better understand the physical basis for this statistical association.

Evidence of an important contrail effect on the daytime radiation budget is provided by recent ground observations of reduced solar irradiance caused by a contrail overcast near Lausanne, Switzerland, on November 4, 1996. Many contrails on this otherwise cloudfree day evolved into a nearly overcast sky by local noon. Global (full sky) and diffuse solar irradiance were measured at local noon