

Validation and Comparison of S-HIS and NAST-I Retrievals for THORPEX 2003

P. Antonelli*, H. E. Revercomb*, R. O. Knuteson*, D. C. Tobin*, S. Dutcher*, W. L. Smith⁺ and D. Zhou⁺

*University of Wisconsin, Madison, Wisconsin; ⁺NASA Langley Research Center, Hampton, VA

Abstract

The Scanning High-resolution Infrared Sounder (S-HIS) and the NPOESS Aircraft Sounding Test-bed Interferometer (NAST-I) have flown simultaneously on the same platform during the 2003 THORPEX Observing System Test (PTOST) campaign. Both the instruments are Michelson interferometers and possess very high spectral and spatial resolution. The results of several airborne missions exploited in the past years have shown that the absolute accuracy of the spectral radiances measured with these instruments is excellent. This paper aims to take advantage of the simultaneous observations collected by the two interferometers and by the other instruments such as the Cloud Physics Lidar (CPL), the MODIS Airborne Simulator (MAS) and Dropsondes, involved in the mission, to show: a) the observation capabilities of S-HIS, b) the relative accuracy of the S-HIS derived products with respect to those derived by the other instruments c) the differences in the vertical and horizontal structure of the retrieved temperature fields between S-HIS and NAST-I.

Introduction

The S-HIS participation to the THORPEX program was aimed to answer the following questions:

- 1) What can be retrieved, in terms of vertical and horizontal resolution, from S-HIS observations?
- 2) How do the S-HIS observing capabilities compare to those of other instruments involved in the experiment?
- 3) How do we make the information about the atmospheric state embedded in the Fourier Transform Spectrometers data available to Numerical Weather Prediction (NWP) models?
- 4) Which impact do the FTS data have on NWP model analysis and forecast?

The work done for PTOST and presented in this paper focuses the first two questions, leaving the third and the fourth one to future work. The paper is divided in two main parts, the first one describes the THORPEX program and its first experiment (PTOST) and the second one describes the results (temperature retrievals) obtained for a specific case study and their validation. A short section dedicated to the conclusions closes the paper.

THORPEX

Overview

THORPEX is a 10 year international research program under the auspices of the World Meteorological Organization/World Weather Research Program (WMO/WWRP) deigned to accelerate improvements in short range (up to 3 days), medium range (3-7 days) and extended range (two week) weather forecast. THORPEX tries to asses the potential to produce significant quantitative and qualitative improvements in forecasts of high impact weather by addressing and examining issues related to predictability and observing system design. The program builds upon ongoing advances within the basic-research and operational-forecasting communities, and aims to enhance the international collaboration between these communities and with users of forecast products. The 2003 Pacific THORPEX Observing System Test (PTOST) is the first in the 10 year series of Pacific and Atlantic observation campaigns in support of the WWRP/USRP THORPEX Program.

Platforms and Instruments

PTOST was conducted from February 18 to March 15, 2003. The campaign focused on the characterization of high-impact weather in the North Pacific north of Hawaii, within the context of the overall objectives of THORPEX. It had objectives regarding tropical cloud characteristics and ocean thermal properties, as well as complimentary satellite validation and aviation weather objectives. The observing platforms and systems used for PTOST/2003 are the NASA ER-2 Aircraft equipped with:

- S-HIS (Infrared) a 0.5 cm^{-1} resolution Fourier transform spectrometer;
- NAST-I (Infrared) a 0.25 cm^{-1} resolution Fourier transform spectrometer;
- CPL (visible), measures backscatter cross-sections of cloud and aerosol particles at 1.064 and 0.532 microns, providing cloud and aerosol backscatter quick-looks, depolarization ratio quick looks, optical depth and cloud boundaries;
- MAS (visible, infrared) a 50-channel multi-spectral imager Fast Ozone Photometer - high altitude /in situ/ ozone concentration.

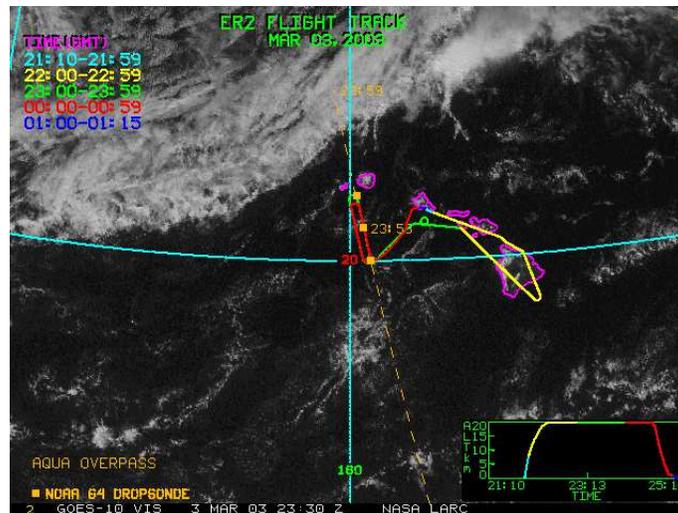


Figure 1: 03 March 2003: ER-2 Flight Track. The yellow squares indicate the locations where dropsondes were released by the G-4.

and the NOAA/G-4 Aircraft, coordinated with the ER-2 and equipped with:

- AVAPS high-density dropsonde system (simultaneous monitoring of 8 dropsondes).
- NOAA Aeronomy Laboratory measurements of ozone and carbon monoxide.
- Flight-level thermodynamic, wind velocity, and turbulence measurements.

The Science Objectives of the PTOST/2003 were: the inter-comparison of forecast skills using NOAA/G-4 dropsonde profiles in observationally sensitive regions versus ER-2 thermodynamic profiles from the S-HIS and NAST-I which are essentially a future sounder simulator (such as GIFTS or HES); the impact of cloud-top temperatures on data assimilation and forecasts given cloud-top heights from the ER2 airborne LIDAR combined with AIRS (Airborne Infra red Sounder), S-HIS, and NAST cloud-top temperature and water vapor phase data.

Case Study

To answer the questions 1 and 2 in the introduction we selected as case study for this paper March 3rd, 2003 (030303). Data were collected between 23:40 and 00:00 UTC of the following day. The ER-2 took off from Honolulu (21:10 UTC), flew South-East, over Big Island of Hawaii (22:30 UTC), North-West toward Kaua'i and then it completed 2 loops (*race tracks*) South of Kaua'i at 00:00 UTC (see figure 1). Four dropsondes were released along the *race track*, South of Kaua'i, by the G-4, between 23:40 and 00:40 UTC, and one radiosonde was launched from Lihue at 00:00 UTC.

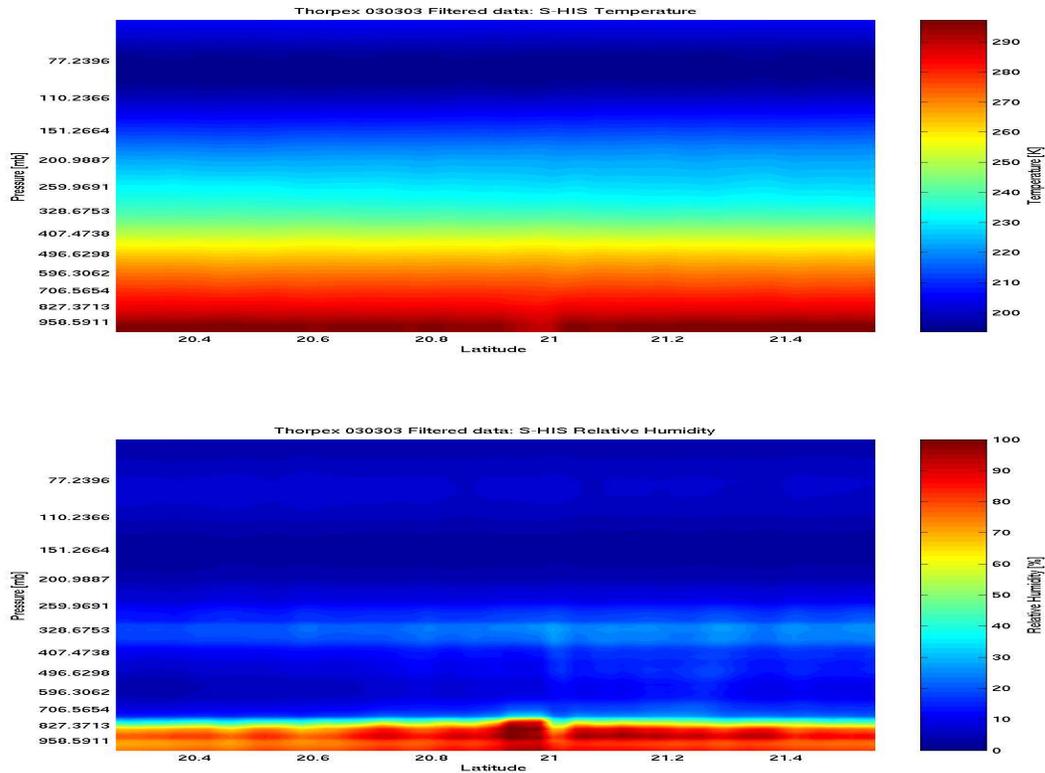


Figure 2: S-HIS VCS for Temperature (top) and Relative Humidity (bottom). The retrieved VCS refer to the flight segment South of Kaua'i between 23:48 and 00:03 UTC.

S-HIS Participation to THORPEX

S-HIS participation to PTOST aimed to provide atmospheric Temperature ($T(p)$) and water vapor Mixing Ratio, or Relative Humidity ($MR(p)$, $RH(p)$) profiles and cloud micro and macro-physical properties. The results showed in this paper focus only on the profiling capabilities of S-HIS. The atmospheric temperature and water vapor fields (figure 2) are retrieved from S-HIS observations using a statistical regression approach used at NASA Langley Research Center [Zhou et al. 2002, Huang and Antonelli 2001].

Validation

The S-HIS retrieved profiles have been validated against the radiosonde launched at Lihue on March 4th, at 00:00 UTC. Figure 3 shows the comparison between the retrieved profiles and the radiosonde profile for temperature (first plot on the left), water vapor $MR(p)$ (second plot from the left), and $RH(p)$ (third plot from the left), as functions of pressure. The fourth plot shows how S-HIS retrieved profiles and of the radiosonde are relatively close in time ($<10 \text{ min}$) and space ($< 30 \text{ Km}$). The comparison of the profiles shows good accuracy of the S-HIS retrieval for both

S-HIS Retrieval Validation. TS: LBLRTM8.1; Unfiltered Data; #pc: 030; Dropsonde: 2003, 03, 04 @ LIH 00:00:00 UTC

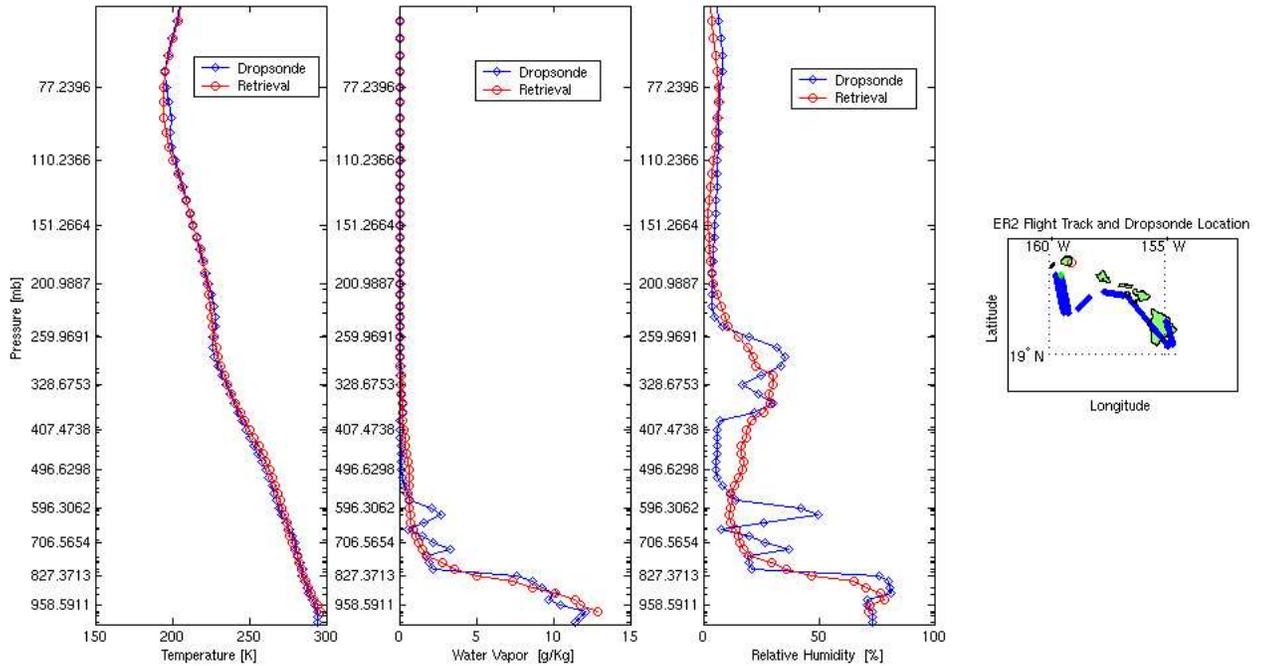


Figure 3: Validation of S-HIS derived temperature and water vapor mixing ratio profiles (red curves). The profiles have been validated against the radiosonde profiles observed at Lihue at 00:00 UTC (blue curves). Starting from the left side the first plot shows the comparison of the temperature vertical profiles. The second and third plots show the comparison between the water vapor mixing ratio and relative humidity vertical profiles. The fourth plot shows the location of the S-HIS retrieved profiles and of the radiosonde. The comparison of the profiles shows good accuracy of the S-HIS retrieval for both temperature and water vapor.

temperature and water vapor.

The profiles have been also validated against the dropsondes released by the G-4 South of Kaua'i. The top plot, in figure 4, shows a Vertical Cross Section (VCS) of the temperature deviation field, obtained interpolating spatially the deviation of 3 dropsonde temperature profiles from their mean. The plot shows an horizontal temperature gradient of about $7 K$ at $250 hPa$. The bottom plot, obtained interpolating spatially the deviation of the 3 S-HIS retrieved temperature profiles (closest in space to the dropsonde) from their mean, shows the same vertical structure of the top plot. This comparison clearly shows the capability of S-HIS to provide valuable information about horizontal atmospheric structures at high spatial resolution ($\sim 2.5 Km$).

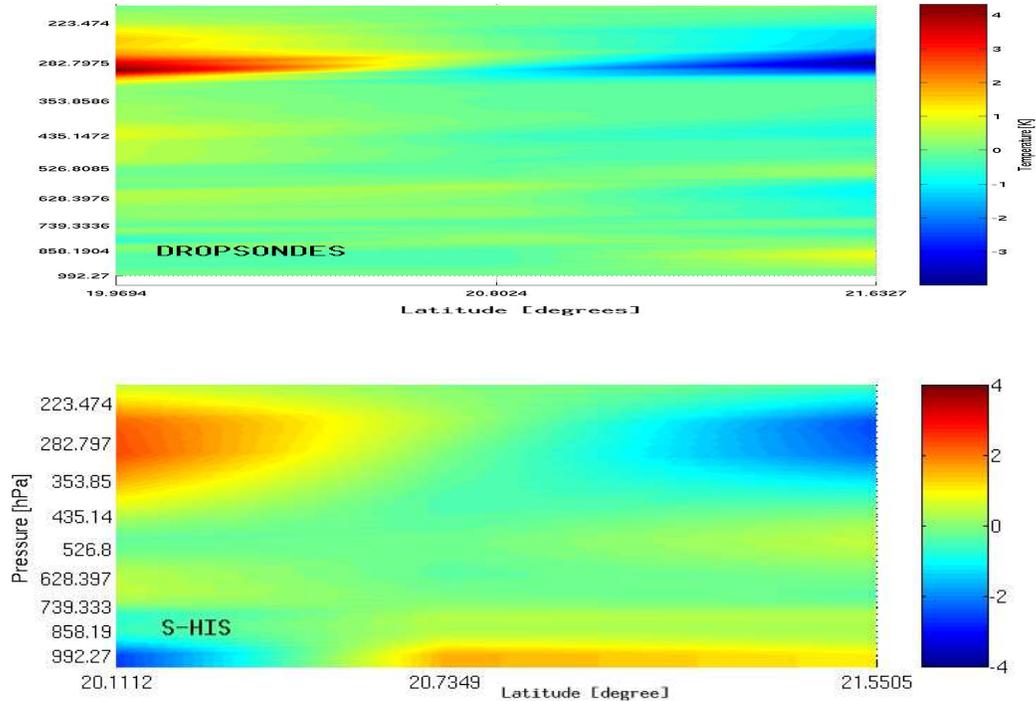


Figure 4: VCS of temperature deviation from the mean. The plots have been obtained interpolating spatially the deviation of 3 dropsonde temperature profiles from their mean (top) and 3 S-HIS retrieved temperature profiles (closest in space to the dropsonde) from their mean (bottom). They both show an horizontal temperature gradient of about 7 K at 250 hPa . The agreement between the images shows the S-HIS capability of accurately *observing* spatial temperature gradients.

Inter-comparison S-HIS, NAST-I

The VCS of the temperature deviation, derived from S-HIS observations, has been also compared to the one derived from NAST-I (courtesy of the NAST-I NASA Langley group). In figure 5 the vertical structures shown in the two cross sections are similar. Both the instruments were able to *observe* the vertical temperature inversion at 12.5 Km of altitude and the strong horizontal temperature gradient ($\sim 7\text{ K}$) at 10 and 15 Km of altitude. But the cross sections still show differences that, considering the similarities between the two instruments, are not expected and have to be further investigated.

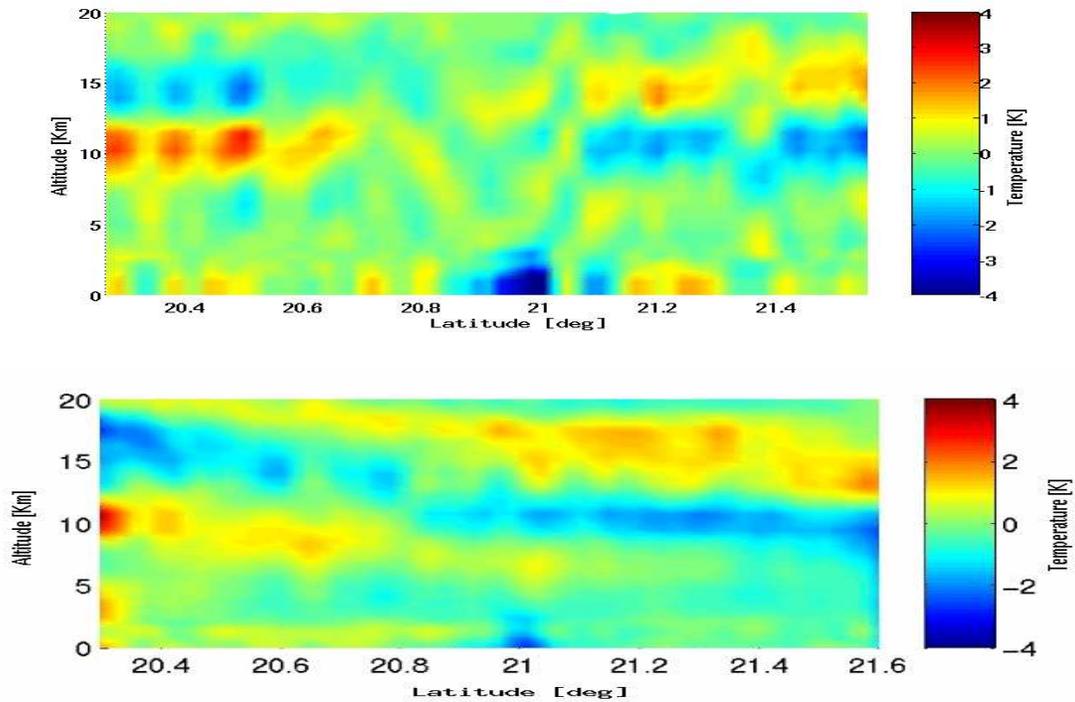


Figure 5: VCS of temperature deviation from the mean. The plots show the VCS as observed by S-HIS (top) and NAST-I (bottom) at full spatial resolution. The comparison of the two cross section shows similarities between the two spatial structures. Both the instruments were able to catch the vertical temperature inversion at 15.5 *Km* and the horizontal gradient at the same temperature. The plots also show differences that have to be further investigated.

Conclusions

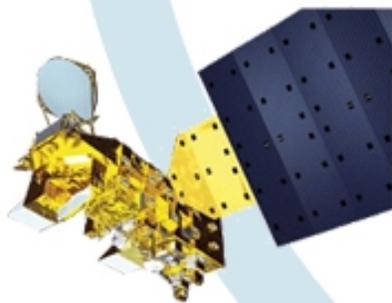
The goal for this paper was to address the issues related to observational capabilities of S-HIS, in terms of vertical and horizontal resolution, and how they compare to the capabilities of other instruments involved in PTOST. With regard to the first question, S-HIS temperature retrievals for the selected case study, have been proved to be in good agreement with radiosonde data (figure 3). They have also been proved to be in good agreement with the profiles measured by the dropsondes released by the G-4. Most importantly S-HIS showed the capability of observing real spatial structures of the atmospheric temperature field that could represent a valuable source of information for NWP models. The S-HIS retrieved temperature field was found to be in good agreement with the NAST-I retrieved field. But the comparison between the temperature retrievals obtained from the two interferometers showed also some differences that were not expected and that should be further investigated.

References

- [Revercomb et al. 1996] Revercomb, H.E.; Smith, W.L.; Best, F.E.; LaPorte, D.D.; Knuteson, R.O.; Werner, M.W.; Anderson, J.R.; Ciganovich, N.N.; Ellington, S.D., and Dedecker, R.G.: *Airborne and ground-based Fourier transform spectrometers for meteorology - HIS, AERI and new AERI-UAV*. Optical Instruments for Weather Forecasting, Proceedings of the Conference, Denver, CO, 8-9 August 1996. Bellingham, WA: Society of Photo-Optical Instrumentation Engineers, 1996. (SPIE Proceedings volume 2832). Pp106-117.
- [Smith et al., 1999] Smith, W.L.; Larar, A.; Hinton, B.; Howell, H.B.; Revercomb, H.E.; DeSlover, D.H.; Sisko, C.A.; Tobin, D.C.; Cousins, D.; Mooney, D.; Gazarik, M., and Mango, S., 1999: *The NPOESS Airborne Sounder Testbed-Interferometer (NAST-I): The validation of results from a new and revolutionary airborne remote sensing tool*. In: Conference on Atmospheric Radiation: A Symposium with tributes to the works of Verner E. Suomi, 10th, Madison, WI, 28 June-2 July 1999 (preprints). Boston, MA: American Meteorological Society; 1999. Pp548-551.
- [Cousin and Gazarick, 1999] Cousins, D. and M.J. Gazarick 1999: *NAST Interferometer Design and Characterization*. Final Report, MIT Lincoln Laboratory Project Report NOAA-26, July 13,1999.
- [Revercomb et al., 1988] Revercomb, Henry E.; Buijs, H.; Howell, Hugh B.; LaPorte, D.D.; Smith, William L., and Sromovsky, L.A. 1988: *Radiometric calibration of IR Fourier transform spectrometers: Solution to a problem with the High-Resolution Interferometer Sounder*. Applied Optics 27(15), 1 August 1988, pp3210-3218.
- [Zhou et al. 2002] D. K. Zhou, W. L. Smith, J. Li, H.B. Howell, G.W. Cantwell, A.M. Larar, R.O. Knuteson, D.C. Tobin, H.E. Revercomb, and S. A. Mango 2002: *Thermodynamic product retrieval methodology and validation for NAST-I*. Applied Optics Vol. 41, No. 33
- [Huang and Antonelli 2001] Hang H-L, P. Antonelli, 2001: *Application of Principal Component Analysis to High-Resolution Infrared Measurements Compression and Retrieval*. Journal of Applied Meteorology, 40, 365-388

Proceedings of the Thirteenth International TOVS Study Conference

INTERNATIONAL
ATOVS
WORKING GROUP



Sainte-Adèle, Québec, Canada
29 October – 4 November 2003