LEO-GEO Stereo Winds: a Demonstration using MODIS and ABI

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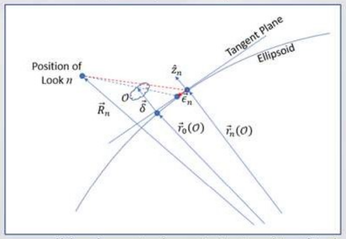
General Stereo Winds Method

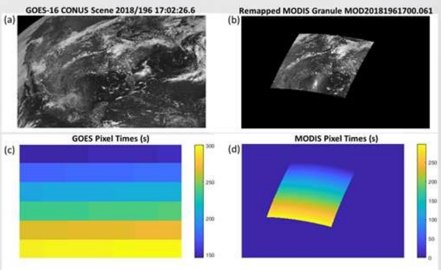
Operational wind products use IR temperatures and a model atmosphere to assign heights to atmospheric motion vectors ("winds") that have been measured by tracking cloud or moisture features in multi-temporal sequences of scenes. Stereo methods seek to improve the accuracy of height assignments and make them independent of a model by using the parallax observed between different platforms to measure geometric height. Stereo methods require geometric accuracy, which is delivered at the subpixel level by the new GOES-R system, MODIS, and VIIRS.



Images from multiple satellites are remapped into a common projection and disparities measured between apparent locations of features. High resolution, subpixel matching accuracy, and accurate geo-registration enable disparities to reveal a combination of parallax from differing poses plus motion due to wind. Simultaneous observation is not required so long as pixels can be accurately time tagged. The retrieval algorithm solves simultaneously for position and velocity states at each designated site. The retrieval estimates $(\vec{\delta}_0, \vec{v})$ for each cloud tracer to model its instantaneous position $\vec{\delta}(t) = \vec{\delta}_0 + \vec{v}\cdot(t - t_0)$. Image $n = 0$ is designated as the reference and disparities are measured with respect to it. The differences between the measured and modeled disparities, $\vec{\epsilon}_n$, are weighted, squared, and summed over all looks n, to be minimized to find the states $(\vec{\delta}_0, \vec{v})$ at each site. The problem is mildly nonlinear and solved iteratively. This general method applies to any imaging system where pixels can be time tagged, including GEO-GEO and LEO-GEO combinations. We have successfully demonstrated the LEO-GEO stereo method using MISR, and more recently, using MODIS.

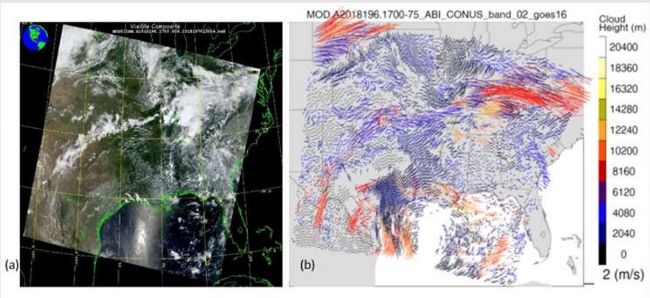
MODIS-ABI Stereo Winds

ABI shares 14 of 16 spectral channels with MODIS, which allows for atmospheric features such as clouds to be tracked in one or more spectral channels whenever MODIS transits an ABI scene. MODIS granules are remapped into the ABI fixed grid along with the times for each pixel (b & d). The method uses a triplet of consecutive ABI scenes (Full Disk, CONUS, or MESO). Pixel times are assigned in accordance with the swath coverage pattern of ABI (c). To preserve the native resolution of MODIS, its granules are remapped into the ABI fixed grid at the native MODIS resolution (twice as fine as ABI) and ABI scenes are up-sampled 2:1. Feature templates are taken from the central repetition, tracked in the other repetitions, and between satellites.



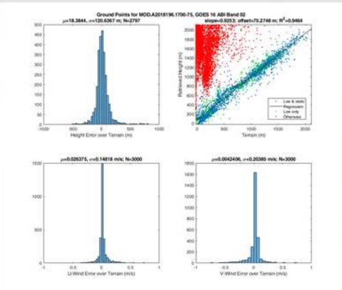
Example MODIS-ABI Stereo Product

A MODIS granule (a) is paired with a triplet of contemporaneous CONUS scenes to produce a stereo winds product (b) using ABI Band 2 and MODIS Band 1. Height is color coded and vectors scale with the speed.

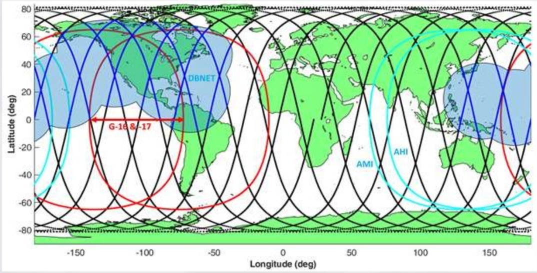


Validation

Clear-sky ground provides an indication of the accuracy of stereo winds by comparing to known terrain heights.



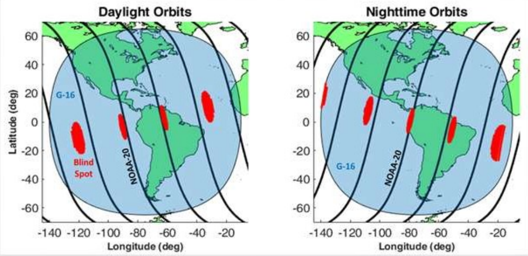
Future Applications with VIIRS



Antenna networks such as NOAA's Direct Broadcast Network (DBNET) offer near real-time access to direct broadcast from polar satellites, including NOAA-20, for latencies similar to GOES-R. This is necessary for an operational LEO-GEO winds product. While in the range of a ground station, the direct broadcast is acquired and processed into a Sensor Data Record (SDR) to be fused with ABI, AHI, AMI, or other GEO imagers (e.g., FCI) to create a stereo winds product. Demonstration or research products don't require low latency and DBNET.

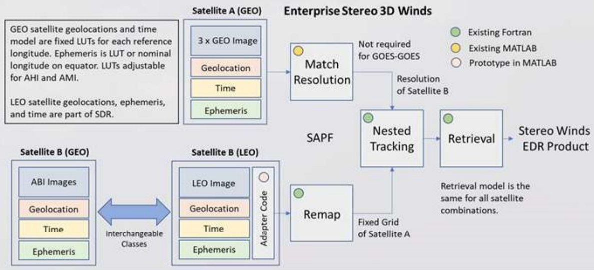
The VIIRS Imaging bands share five wavelengths with ABI and her sister imagers. This enables stereo winds to be extended beyond where there is overlapping GEO coverage, including the Atlantic Ocean region critical for tropical cyclones. VIIRS I4 (3.9 μm) and I5 (11.2 μm) have 375 m resolution, while the matching ABI bands have 2 km resolution. The higher resolution improves the perception of texture in the cloud-tracer templates to enable finer spatial resolution for stereo IR winds.

For each JPSS-GEO satellite pair, there will be typically six daylight passes where all five imaging bands can be used, and six nighttime passes where only I4 and I5 can be used (right). As with MODIS, when the VIIRS line-of-sight is parallel to that of the GEO satellite, stereo methods cannot retrieve the height. This leaves small blind spots near the JPSS ground track where the binocular separations is < 10°. Otherwise, stereo winds can be produced over the Full Disk of each GEO.



Enterprise Stereo Winds

The same algorithms are used for both LEO-GEO and GEO-GEO combinations, which allows one of the satellite pair to be interchanged LEO-for-GEO within the STAR Algorithm Processing Framework (SAPF), making stereo winds an Enterprise Algorithm. Most pieces of the Enterprise Algorithm exist already as Fortran or protype MATLAB code and have been proven using MODIS and GOES-R. This approach applies to NOAA international partner spacecraft too.



Publications

Carr, J.L., D.L. Wu, R.E. Wolfe, H. Madani, G. Lin, B. Tan, "Joint 3D-Wind Retrievals with Stereoscopic Views from MODIS and GOES", *Remote Sensing*, 2019, Satellite Winds Special Issue; https://doi.org/10.3390/rs11182100.

Carr, J.L., D.L. Wu, M.A. Kelly, and J. Gong, "MISR-GOES 3D Winds: Implications for Future LEO-GEO and LEO-LEO Winds", *Remote Sensing*, 2019, MISR Special Issue; doi: 10.3390/rs10121885.

Horváth, Á., W. Bresky, J. Daniels, J. Vogelzang, A. Stoffelen, J.L. Carr, D.L. Wu, C. Seethala T. Günther, S.A. Buehler "Evolution of an atmospheric Kármán vortex street from high-resolution satellite winds: Guadalupe Island case study", *Journal of Geophysical Research: Atmospheres*, 125, 2020, https://doi.org/10.1029/2019JD032121.