Module 3.1

Slide 1: An additional instrument on GOES that we have not yet discussed in great detail is the Geostationary Lightning Mapper, or GLM. It detects lightning flashes over a large disk, something that no other instrument is capable of doing. This module will describe how GLM works and discuss global lightning distributions.

Slide 2: Detection of lightning has several benefits. From a research perspective, a long time period of lightning data can inform about how the electrical field balance on Earth evolves. Lightning is also an important indicator of intense convection and reveals some information about the microphysical and dynamical structures of clouds. For example, many have associated lightning in tropical cyclones with intensification of the storm because it signifies the existence of intense updrafts. Lightning detection has economic and societal utility as well. For example, it can provide early detection of developing severe thunderstorms. Ground-based lightning detection systems, the subject of the next module, provide warning of nearby electrical activity or augment the research capabilities of lightning detection from space.

Slide 3: An exact understanding of how lightning occurs has not yet been reached, but the basic mechanism is as follows: Here is a cloud that may become electrified, and here is a person on the ground.

Slide 4: The ground may take on a positive or negative charge, while in the cloud, ice collision processes cause negative charge to accumulate in the middle to lower parts of the cloud as the larger, falling graupel becomes negatively charged, while smaller rising ice crystals in updrafts become positively charged and are lofted to the top of the cloud. A thin layer near cloud base is also sometimes positively charged. The ground may be positively or negatively charged.

Slide 5: Lightning occurs when a large electrical potential develops. This may occur between opposite charges in neighboring clouds, within a single cloud—known as intra-cloud lightning, or between the cloud and the ground, known as cloud-to-ground lightning, or CG. In this example, the lightning begins as a leader extending from the negative charge in the cloud toward the positive charge at its base. The negatively charged leader moves toward the surface.

Slide 6: As the leader approaches the surface, the electric potential near the ground increases, and an upward streamer can develop where the potential is greatest.

Slide 7: The upward streamer meets the downward leader, and

Slide 8: discharge occurs, reducing the electrical potential. This is the visible lightning flash. During this flash, the surrounding air heats up to tens of thousands of degrees, emitting visible light as well as other wavelengths.

Slide 9: The charge is then reduced at the cloud and ground until it rebuilds.

Slide 10: The annual mean lightning strike frequency globally is shown here. It is actually derived from a ground-based network of sensors since we have not yet had continuous global detection of lightning from space. Lightning is more frequent over land—particularly over northwestern South America, the southeastern US, central Africa, and the Maritime Continent. Less lightning is detected over ocean.

Slide 11: From space, lightning detection has been limited to a few instruments that observed only small areas at once. For example, the Optical Transient Detector flew aboard MicroLab-1 in the 1990s and the Lighting Imaging Sensor was aboard the TRMM satellite. The GLM design is based on the same concept as the two formerly operating instruments. Because it is in geostationary orbit, it views the largest area of any space-borne lightning sensor used to date, covering up to 52 degrees latitude. Thus, the major benefit of space-borne lightning detection is continuous observation of a large area. The main negative is that the spatial resolution—only 8–14 km wide grid boxes depending on distance from nadir—means that precisely locating a lightning strike is not possible. All of the spaceborne lightning detectors work on a simple concept. At 777 nm—in the near infrared—there is a narrow oxygen absorption band at which the vertical path direct transmittance of the atmosphere is only about 80%. Oxygen is ubiquitous in Earth's atmosphere and is well-mixed horizontally. Therefore, atmospheric emission of near-IR photons at 777 nm is dependent only on the air temperature. At normal temperatures, air emits in the terrestrial part of the IR spectrum, around 10 microns. When lightning heats oxygen molecules, the air becomes hot enough such that its Planck emission spectrum shifts temporarily toward much shorter wavelengths. Spaceborne lightning sensors detect the emitted radiation at 777 nm by heated oxygen molecules.

Slide 12: The instrument itself is very large, standing almost 5 feet high if measured lengthwise.

Slide 13: One example of GLM data is shown here. The yellow and orange flashes denote lightning strikes during an evening in the Amazon. About one-third of the way through, the co-location of lightning and developing cumulonimbus clouds is obvious.

Slide 14: Flashes are detected by searching for persistently higher emissions than the background average over short periods of time. The background average is computed frequently. Pixels that exceed the average are considered "events". Adjacent events occurring near each other at the same time are considered a "group" of events. A single flash is a sequential group in space and time separated by less than 330 ms and 1–2 grid points. See the link at the bottom for more details and some helpful graphics. (http://rammb.cira.colostate.edu/training/visit/quick_guides/GLM_Quick_Guide_Detection_Methods_June_2018.pdf)

Module 3.2

Slide 1: In this module, we will look over some ground-based lightning detection networks, which operate using fundamentally different mechanisms than GLM.

Slide 2: Ground-based lightning detection networks operate at VHF or VLF, which are both wavelengths in the radio part of the EM spectrum. Both have benefits. VLF radio waves can travel farther because they are less attenuated by the atmosphere; however, VHF signal from lightning flashes is usually greater. Ground-based lightning detections work via one of two mechanisms.

Slide 3: The first is the time of arrival technique. It works by using at least three sensors that detect the same lightning flash. Suppose Receiver 1 and 2 both detect a lightning flash. Suppose a lightning strike, the red dot, occurred closer to Receiver 1 than Receiver 2. The emission from the flash would reach Receiver 1 first. Therefore, some delay would be observed between Receivers 1 and 2. That delay tells us that the flash must have been somewhere along the up-and-down pointing hyperbola, but we cannot pinpoint where exactly along the hyperbola the flash occurred. However, if Receiver 3 also detects the signal—in this case—just a little before Receiver 2, then the additional delay in the signal arrival at Receivers 2 and 3 defines another hyperbola along which the lightning flash could have occurred. The intersection of the two hyperbolas is the location of the flash.

Slide 4: The direction-finding technique uses directionally oriented sensors to detect in what direction a strike occurred. However, a single sensor contains no information about how far away the strike occurred. Additional sensors can better constrain the location of the strike; however, the possible location of the strike increases with distance from the nearest sensor.

Slide 5: Seen here are a few old,

Slide 6: and newer versions of ground-based lightning sensors.

Slide 7: The US National Lightning Detection Network is a proprietary network of both DF and TOA sensors located throughout the continental US. It has very high efficiency at detecting cloud-to-ground strikes, even during daytime, when GLM detection is more challenging in a background of reflected solar radiation. The median location accuracy is less than 200 meters, making it a much more precise method of locating lightning than GLM. However, while such a dense network is excellent for lightning detection over land, its detection efficiency falls off rapidly as one moves away from land.

Slide 8: Worldwide networks operating in VLF, such as WWLLN, can provide global lightning detection. In VLF, less attenuation occurs; therefore, the emitted radio signal of lightning can be detected several hundred kilometers from a strike. However, because the VLF emissions by lightning are small, only 20–30% of strikes are detected. WWLLN can provide highly accurate locations of lightning; however, GLM is more reliable at detecting lightning strikes over ocean at the expense of less precise geolocation.

Slide 9: An example of WWLLN data is shown here. The blue marks represent lightning strikes, and the red stars indicate locations of ground-based stations.

Slide 10: Other networks do exist. Some large area networks, such as ENTLN, use VHF so that the networks can better detect intra-cloud flashes. However, because VHF is more attenuated as it passes through the atmosphere, more sensors are required to reach full global coverage.

Slide 11: Some interesting videos can be seen at the site linked here (http://lightning-interferometry.com/index.php/videos/). It contains some videos of lightning detected via interferometry. While not an application for lightning detection, the videos show details of the evolution of lightning strokes at five to ten thousand frames per second.