DOE/SC-ARM-12-020

MAGIC: Marine ARM GPCI Investigation of Clouds

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October 2012

CLIMATE RESEARCH FACILITY

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Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Summary

Clouds remain a major source of uncertainty in climate projections. In this context, subtropical marine boundary layer (MBL) clouds play a key role in cloud-climate feedbacks that are not well understood yet play a large role in biases both in seasonal coupled model forecasts and annual mean climate forecasts. In particular, current climate models do not accurately represent the transition from the stratocumulus (Sc) regime, with its high albedo and large impact on the global radiative balance of Earth, to shallow trade-wind cumulus (Cu), which play a fundamental role in global surface evaporation and albedo. Climate models do not yet adequately parameterize the small-scale physical processes associated with turbulence, convection, and radiation in these clouds. Part of this inability results from lack of accurate data on these clouds and the conditions responsible for their properties, including aerosol properties, radiation, and atmospheric and oceanographic conditions.

The second Atmospheric Radiation Measurement (ARM) Mobile Facility (AMF2) will be deployed aboard the Horizon Lines cargo container ship merchant vessel (M/V) *Spirit* for MAGIC, the Marine ARM GPCI1 Investigation of Clouds. The *Spirit* will traverse the route between Los Angeles, California, and Honolulu, Hawaii, from October 2012 through September 2013 (except for a few months in the middle of this time period when the ship will be in dry dock). During this field campaign, AMF2 will observe and characterize the properties of clouds and precipitation, aerosols, and atmospheric radiation; standard meteorological and oceanographic variables; and atmospheric structure. There will also be two intensive observational periods (IOPs), one in January 2013 and one in July 2013, during which more detailed measurements of the atmospheric structure will be made.

The primary objectives of MAGIC are to improve the representation of the Sc-to-Cu transition in climate models by characterizing the essential properties of this transition, and to produce the observed statistics of these Sc-to-Cu characteristics for the deployment period along the transect. This first marine deployment of AMF2 will yield an unparalleled and extremely rich data set that will greatly enhance the ability to understand and parameterize clouds and precipitation, aerosols, and radiation and the interactions among them; the processes that determine their properties; and factors that control these processes. Deployment of AMF2 on a ship that routinely traverses this transect will provide a long-term data set over a vast cloud region which is of intense interest to climate modelers. Specifically, the proposed transect lies closely along the cross-section used for the GPCI1, and the data collected will provide constraint, validation, and support for this modeling effort, and for associated modeling efforts such as CFMIP2, CGILS3 and EUCLIPSE4. The founders of ARM recognized the importance of these marine cloud regimes, and the original document recommending locales for ARM sites (ARM 1991) explicitly called for sites in the Eastern North Pacific or Eastern North Atlantic Ocean. The MAGIC deployment will meet the identified requirement for ARM measurements in this region.

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[1] GPCI: Global Energy and Water Cycle Experiment (GEWEX) Cloud System Studies (GCSS) Pacific Cross-section Intercomparison

[2] CFMIP: Cloud Feedback Model Intercomparison Project

[3] CGILS: CFMIP-GCSS Intercomparison of Large Eddy Models and Single Column Models, a joint project of the GCSS and the World Climate Research Programme Working Group on Coupled Modelling Cloud Feedback Model Intercomparison Project (CFMIP)

[4] EUCLIPSE: European Union Cloud Intercomparison, Process Study & Evaluation Project

Acronyms and Abbreviations

3D	three-dimensional
ACSM	aerosol chemical speciation monitor
ADCP	acoustic Doppler current profiler
AIRS	Atmospheric Infrared Sounder
AMF	ARM Mobile Facility
AOS	aerosol observing system
ARM	Atmospheric Radiation Measurement (Climate Research Facility)
ASR	Atmospheric System Research
CIP	Construction and Installation Plan
CCN	cloud condensation nucleus
CFMIP	Cloud Feedback Model Intercomparison
CGILS	CFMIP-GCSS Intercomparison of Large Eddy Models & Single Column Models
CRM	cloud-resolving model
Cu	cumulus
DOE	U.S. Department of Energy
ECMWF	European Centre for Medium-Range Weather Forecasts
EUCLIPSE	European Union Cloud Intercomparison, Process Study & Evaluation Project
GCM	global climate model
GCSS	GEWEX Cloud Systems Study
GEWEX	Global Energy and Water Cycle Experiment
GPCI	GCSS Pacific Cross-section Intercomparison
IOP	Intensive Observational Period
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Intertropical Convergence Zone
KAZR	Ka-band ARM zenith radar
Knts	knots
LES	large-eddy simulation
LWP	liquid water path
MAGIC	Marine ARM GPCI Investigations of Clouds
MBL	marine boundary layer
MPL	micropulse lidar
M/V	merchant vessel
M-WACR	marine W-band ARM cloud radar
MWR	microwave radiometer
NASA	National Aeronautics and Space Administration
PI	principal investigator

RH	relative humidity
Sc	stratocumulus
SCM	single-column model
SST	sea surface temperature
TSG	thermosalinograph
UTC	Coordinated Universal Time

Contents

Figures

Tables

1.0 Introduction

Clouds are essential to Earth's climate, weather, radiation budget, and hydrological cycle, but despite this great importance, many aspects of their properties and their roles in various processes are not well understood. Important reasons for this lack of understanding are:

1. the vast range of spatial scales on which cloud processes occur—from nanometer-scale phenomena such as cloud drop activation, to mesoscale phenomena such as pockets of open cells, to synoptic scale phenomena such as midlatitude cyclones
2. their high temporal variability, with some clouds lasting only minutes
3. the three-dimensional (3D) nature of clouds, making determination and representation of their shape difficult.

The description and parameterization of clouds in global climate models (GCMs), with time steps of hours and length scales of tens of kilometers, are still relatively primitive, and understanding of cloud processes is still evolving.

Because of their vast extent, marine clouds play an especially critical role in the global radiation budget and hydrological cycle, and thus in climate and climate change. However, most non-satellite investigations of such clouds have been on relatively short-term (~1 month) research cruises or aircraft campaigns in fairly small regions. Non-satellite characterization of cloud properties and their temporal and spatial variability over large regions of the oceans for extended periods (i.e., months to years) has not been made. Among all marine clouds, clouds in the marine boundary layer (MBL) in particular exert an outsized influence on climate and climate change, but this influence also remains poorly understood in spite of many field campaigns, with large differences among models resulting from differing parameterizations of cloud properties (e.g., Bony and Dufresne 2005, Andrews et al. 2012). Likewise, there are large differences in the radiative influences of clouds among current climate models and between models and observations (e.g., Bender et al. 2006). These differences translate, among other things, into poor knowledge of the effects of increasing greenhouse gas concentrations (and the resultant warming) on clouds, which constitute the largest uncertainty in modeled climate sensitivity (IPCC 2007).

Marine clouds and their behavior are inexorably coupled to other components of the environment. Surface fluxes of sensible and latent heat, which are controlled by atmospheric structure and oceanic conditions, determine many characteristics of the cloudy MBL and are in turn influenced by clouds. Aerosols affect clouds by providing nuclei upon which cloud drops are formed, with the number concentration and sizes of cloud drops depending on the sizes and compositions of these nuclei. In turn, aerosols are affected by clouds through chemical processing within cloud drops and by removal through in-cloud or below-cloud scavenging. Absorption of shortwave radiation by clouds can lead to evaporation; in turn clouds affect Earth's radiative balance by scattering incoming shortwave radiation and by absorbing and re-emitting outgoing longwave radiation. Thus the ability to understand clouds and improve their representation in models requires high quality data sets not only of clouds and cloud properties, but also of oceanic and atmospheric conditions (i.e., sea surface salinity, temperature, and velocity, and vertical profiles of atmospheric temperature, relative humidity, and wind velocity), aerosols properties (concentration, size distribution, and composition, which is often inferred from measurements of hygroscopic growth, light scattering, and cloud formation properties) and radiative properties (vertical profiles of shortwave and longwave upwelling and downwelling radiation).

Because of the importance of MBL clouds to the global climate system, several modeling projects have been developed to better understand and parameterize these clouds in GCMs. In particular, GCSS (GEWEX [Global Energy and Water Cycle Experiment] Cloud System Studies), an international group of cloud modelers, has chosen a transect extending from 35°N, 125°W to 1°S, 173°W (from the western coast of the U.S. heading southwest to the equator; see Figure 1) to compare model results for the GCSS Pacific Cross-section Intercomparison (GPCI). Of particular interest are the types of clouds and the transitions between different cloud regimes, which are poorly represented in models. The inability to accurately represent these transitions in models is the cause of one of the largest uncertainties in knowledge of cloud feedback on climate.

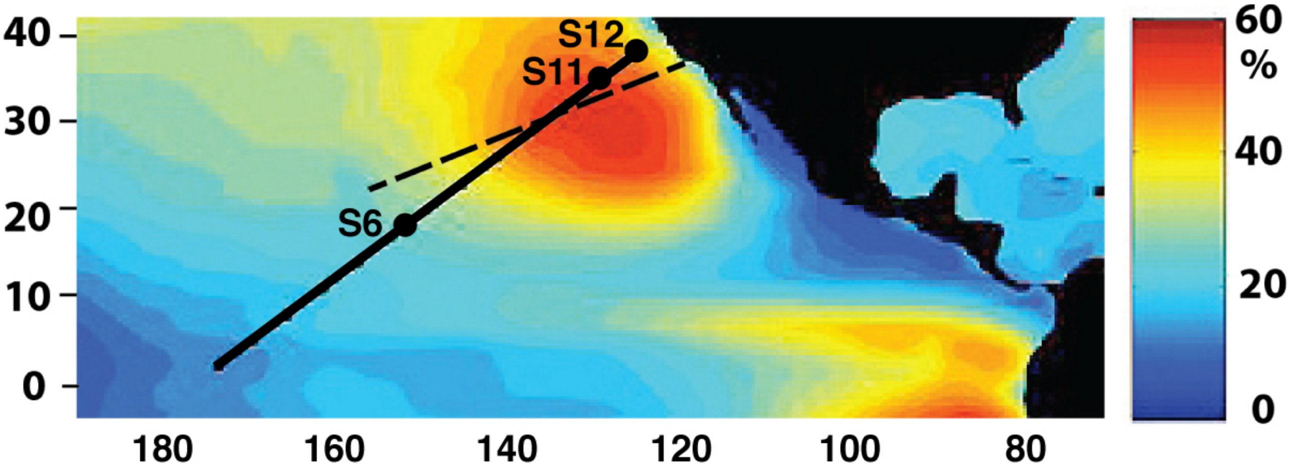

Figure 1. Annual average low-level cloud cover from ISCCP (International Satellite Cloud Climatology Project), with Horizon Spirit route (dashed) from Los Angeles to Honolulu and GPCI transect (solid), along which Points S6, S11, and S12 used in CGILS are also shown.

The cloud type and cover along this transect from east to west vary from low marine Sc with high coverage near the California coast to puffy Cu with much lower coverage in the trade-wind regions near Hawaii to patchy high cumulus near the equator (Figure 1). The low marine Sc decks, with their high albedo and large areal coverage, provide an extremely important forcing of Earth's climate. The trade Cu play a large role in the global surface evaporation and also Earth's albedo. The Sc regions are accompanied by lower sea surface temperatures (SSTs), with transition occurring by Cu formation under Sc, and then Sc evaporation leaving a patchy Cu layer which is accompanied by higher SST (Wyant et al. 1997, Bretherton and Wyant 1997). Probabilities of cloud thermodynamic quantities such as liquid water path (LWP) also change east to west along this transect from Gaussian to skewed, and the MBL height increases from typical values near 500 m to more than 1 km. Additionally, the mean SST in June, July, and August increases from ~290K to ~297K, and the relative humidity (RH) in the lowest several meters above the sea surface increases from slightly below 80% to near 90%. The SST has a strong influence on cloud properties through the fluxes of latent and sensible heat from the sea surface.

GCSS was initiated in the early 1990s (Browning et al. 1993, Randall et al. 2003) with key objectives being developing the scientific basis for the parameterization of cloud processes and promoting the evaluation and intercomparison of parameterization schemes for cloud processes. GPCI was a working group within GCSS (now Global Atmospheric System Studies, or GASS), whose main goal was to evaluate and improve how climate and weather models represent subtropical and tropical cloud regimes and transitions between them, particularly the Sc-to-Cu transition.

In the GPCI study, models were analyzed along a cross-section from the Sc regions off California, across the shallow convection trade-wind areas, to the deep convection regions of the Intertropical Convergence Zone (ITCZ) (Figure 1). This approach took GCSS, whose other working groups focused on a single cloud type, in the direction of increased generality by providing a framework for 3D model evaluation that includes several connected cloud regimes: Sc, shallow Cu, deep Cu, and the transitions between them. More than twenty weather and climate models participated in the first phase of GPCI (Teixeira et al. 2011), which provided a detailed characterization of how models represent the Sc-to-Cu transition and helped identify some key model shortcomings. The results confirmed previous problems with climate models such as underestimating cloud amounts in the Sc regime and overestimating clouds in the shallow Cu regime, with corresponding consequences for shortwave radiation; large spread in cloud cover, LWP, and shortwave radiation among the models (Figure 2); and large inter-model differences of vertical properties of clouds, vertical velocity, and surface RH. GPCI has been a useful forum for confronting these models with the newest generation of satellite data sets. It has also been demonstrated that those climate and numerical weather prediction models that have actively worked on further developing the representation of cloud related processes have shown a significant improvement of the representations of these two cloud regimes.

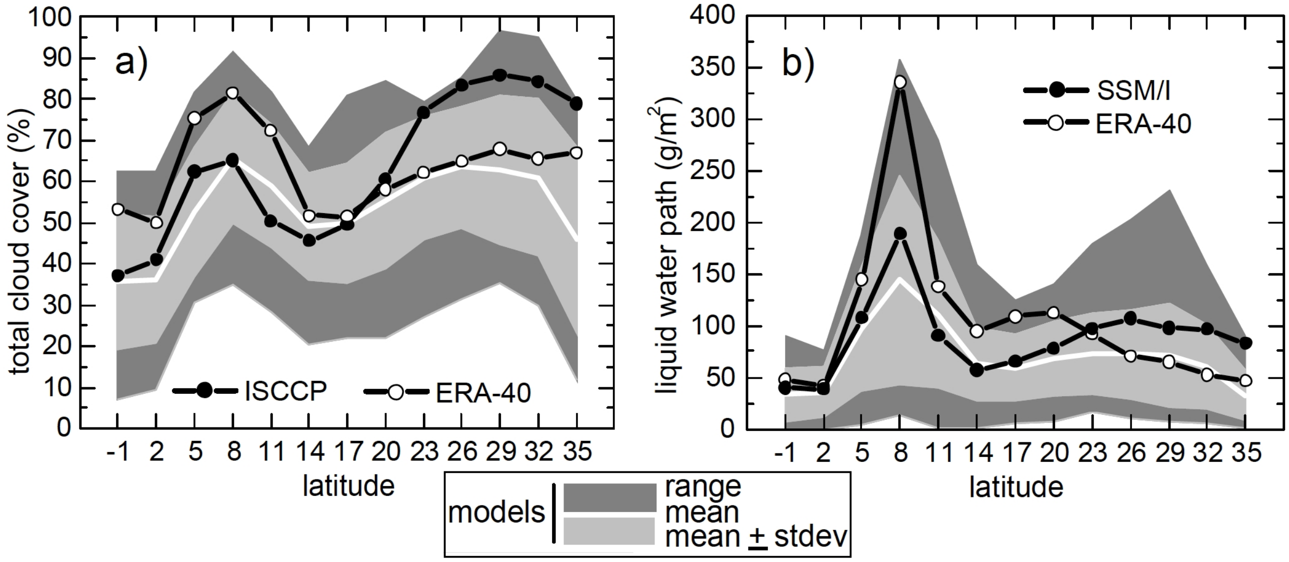

Figure 2. Model results for a) total cloud cover, and b) total LWP, along GPCI for JJA 1998, shown as ensemble results from 23 models, the mean plus or minus the standard deviation; range extends from minimum to maximum values. Also shown are results from ISCCP, European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis (ERA-40), and Special Sensor Microwave Imager (SSM/I). From Teixeira et al. 2011.

Another modeling effort, CGILS (a joint project of the GCSS and the World Climate Research Programme Working Group on Coupled Modelling CFMIP) focuses on the marine Sc and Cu clouds along the GPCI transect, specifically the following locations:

- S12 (35°N, 125°W), characterized by shallow coastal Sc
- S11 (32°N, 129°W), near the climatological summertime maximum of low-level cloud cover
- S6 (17°N, 149°W), characterized by shallow Cu (Figure 1).

CGILS uses idealized large-scale dynamical conditions to evaluate subtropical MBL cloud feedback processes in GCMs. Its objectives are to understand the physical mechanisms of these feedbacks in GCMs by using single-column models (SCMs) and to assess the physical credibility of low-cloud processes in the SCMs by using cloud-resolving models (CRMs) and large-eddy simulations (LESs). Advantages to this approach are that it isolates the model physics from the dynamics (greatly simplifying the problem), allows use of LES to be compared with SCMs forced under identical conditions, and allows determination of the sensitivity of simulated clouds to different aspects of the large-scale dynamics conditions. The initial study, involving S11, included 16 SCMs and 5 LES models.

EUCLIPSE, a collaborative effort of twelve institutes throughout Europe, is designed to improve the evaluation, understanding, and description of the role of clouds in the Earth's climate focusing on the cloud feedback in a warming climate. Its central objective is reducing the uncertainty in the representation of cloud processes and feedbacks in the new generation of earth system models in support of the IPCC's fifth Assessment Report. Nine climate and weather prediction models participated in the first EUCLIPSE intercomparison (Siebesma et al. 2004), which used the GPCI transect. It was found that although there was much inter-model variation, nearly all models strongly underpredicted cloud cover and amount in the Sc regions while overpredicting these quantities in the Cu region.

A fundamental limitation to further progress in all these activities has been the lack of observational data to constrain the models and evaluate how they represent the Sc-to-Cu transition. Most of the observational data sets used to evaluate the cloud related processes are top-of-the-atmosphere data (radiation) or vertical integrated data (water vapor, cloud cover), while the new products that have vertical resolution (such as Cloudsat and Atmospheric Infrared Sounder [AIRS]) are unreliable in the lowest kilometer of the atmosphere. Thus, although these activities have been successful in evaluating biases in cloud representation in climate models, the lack of near-surface observational data inhibits identification of the physical origins of these biases. It is therefore essential to have complementary observations from the surface, both in situ as well as remote sensed, such as surface fluxes (radiation, latent and sensible heat); cloud properties (fractional coverage, base height, thickness, water content); MBL height; cloud dynamics (e.g., updraft velocities); and profiles of temperature, humidity, and wind in the lowest kilometers. AMF2 and the additional instrumentation on this deployment will provide many of these necessary observations. Each of the modeling studies described above is poised to make immediate use of the data from this deployment. In particular, GPCI and EUCLIPSE will undertake new model intercomparisons solely because of this deployment, and the MAGIC data will be central to a planned CGILS seasonal contrast study.

2.0 Deployment Site

The MAGIC deployment will be on board the Horizon Lines cargo container *Spirit* (Figure 3), which makes round trips along a great circle route from Los Angeles, CA (33.7°N, 118.3°W) to Honolulu, HI (21.3°N, 157.9°W) every two weeks. During the voyage from Los Angeles, the *Spirit* travels at ~21 kts (~10.5 m s^{-1}) and covers the 4100 km in 4.5 days. After approximately 24 hrs in port in Honolulu for unloading and loading, the *Spirit* returns to Los Angeles at ~16 kts (~8 m s^{-1}), making the trip in ~6.5 days. The ship is in port at Los Angeles for approximately 48 hrs before returning to Hawaii.

Figure 3. *Horizon Spirit*.

Three AMF2 containers will be on the bridge deck of the *Spirit*, and other instrumentation will be positioned around the bridge, its railings, and on the bridge deck and mast. The planned location of the containers and instruments is described in the Construction and Installation Plan for MAGIC (CIP 5-12, 2012). The bridge deck is ~20 m above the water line (depending on loading), and the bridge roof is approximately 3 m higher. The bridge area is expected to receive marine air that is largely unperturbed by ship contamination, as the ship is a steam ship with two stacks at midship. At least two technicians will be on board the ship to operate AMF2 and to launch weather balloons with radiosondes. Four radiosondes will be launched each day, at 0:00, 06:00, 12:00, and 18:00 UTC, except during the two IOPs, which will occur during one round trip from Los Angeles to Hawaii in January and July 2013, during which more frequent soundings (eight per day instead of the usual four) will be made to provide a more detailed picture of the atmospheric structure and its daily cycle in two different seasons.

Three MAGIC/ARM personnel rode the ship in February 2012 to observe conditions, investigate weather balloon launches, make meteorological measurements, and characterize the ship motion. This Leg0 proved extremely valuable in estimating the range of conditions that can be expected during MAGIC. Information on this leg can be found in the Leg0 Cruise Report (Lewis et al. 2012).

The *Spirit* route from Los Angeles to Honolulu lies in a region of great climatic importance. As discussed above, the typical cloud type and cover along this route vary from low marine Sc with high coverage near the California coast to puffy Cu with much lower coverage in the trade-wind regions near Hawaii (Figure 1). Cirrus are also common. The *Spirit* route lies close to the GPCI transect and passes through the same cloud regimes GPCI is investigating. Other modeling activities also use this route or points along it for model evaluation and intercomparisons, making the data from MAGIC extremely valuable for these activities.

3.0 Science Goals

The primary objectives of MAGIC are to improve the representation of the Sc-to-Cu transition in climate models by characterizing the essential properties of this transition and to produce the observed statistics of these Sc-to-Cu characteristics for the deployment period along the transect. These goals will necessitate measurements of the following:

- Properties of clouds and precipitation: specifically cloud type, fractional coverage (as a function of height), cloud boundaries (base, height), physical thickness, LWP, cloud and liquid water content (as a function of height), cloud drop number concentration, size distribution, and effective radius, cloud optical depth, and drizzle and precipitation frequency, drop size distribution, amount, and extent.
- Atmospheric conditions: specifically temperature, pressure, RH, wind speed and direction, and the vertical profiles of these quantities, including boundary-layer height and inversion strength.
- Properties of aerosols: specifically concentration, size distribution, light-scattering behavior, hygroscopic behavior, cloud condensation nuclei (CCN) behavior, and composition. Although not measured during this deployment, individual particle composition would have been especially valuable, as it provides information on mixing state and could be used to identify source regions.
- Spectral and broadband shortwave and longwave radiation and their interaction with clouds and aerosols: specifically broadband and narrow-channel direct and diffuse fluxes, downwelling and upwelling spectral radiances, and cloud and aerosol spectral optical thicknesses.
- Surface fluxes of momentum, moisture, and latent and sensible heat.
- Oceanographic conditions: specifically sea state and sea surface temperature, salinity, and current speed and direction. These measurements are necessary for computation of vertical fluxes of sensible and latent heat and for identifying factors that control cloud properties, especially cloud types and their transitions.

4.0 Measurement Requirements

Measurements of many of the required quantities listed above will be made with the instruments in AMF2 (the current instrument list is provided in the next section). As accurate knowledge of atmospheric structure and boundary-layer transitions is of utmost importance to MAGIC, sonde launches will be made every six hours at 0:00, 06:00, 12:00, and 18:00 UTC during regular operations, and every three hours at 00:00. 03:00, 06:00, 09:00, 12:00, 15:00, 18:00, and 21:00 UTC during two IOPs (in January 2013 and July 2013, each lasting one round trip) to provide more detailed information on atmospheric structure, boundary-layer transitions, and their seasonal variability.

Although ARM has considerable experience making land-based measurements of many of the required quantities, ship-based measurements are much more challenging. Environmental conditions are harsh, requiring consideration of effects of wind, corrosion, soot, vibration, jarring, power availability, and a host of other issues, many of which cannot be foreseen. Most of the instruments are not specifically designed for shipboard measurements, and the performance of many of them at sea is untested.

There are several key concerns with ship-based measurements. First, the ship does not remain at a fixed location, and this motion imposes stringent conditions on sampling rates, as the relative motion of clouds may be much greater than it would be from a fixed site. The ship moves at ~10 m s 1, and wind speeds at the surface can have comparable levels, with those at cloud height even greater. At relative winds of 25 m s 1, for instance, the ship will move 100 m (the length of a small cumulus) in 4 s. Thus, all measurements of cloud properties using lidars, ceilometers, and other cloud instruments must be made considerably more frequently than this time to attain adequate resolution of such clouds.

An additional difference between ship-based and land-based deployments is that the ship does not retain a fixed orientation (characterized by pitch, roll, and yaw). As this factor affects vertically pointing instruments and those such as radiometers that require accurate knowledge of sun position, accurate knowledge of orientation and vertical and angular velocities is necessary for correction of data from radars (for Doppler spectra, for instance) and other instruments. Motion of an instrument in the vertical direction due to ship motion (heave) will also affect determination of Doppler spectra. Based on the data collected during Leg0, measurements of pitch/roll/yaw and the three components of translational motion, plus the accelerations of these quantities, at 10 Hz should be sufficient to account and correct for ship motion.

Both ship motion and changing orientation necessitate real-time and post-processing of some datastreams beyond what is required for land-based measurements. Other concerns facing shipboard measurements are screening by ship structures, which limits views of the sky; ship effects on meteorological and radiation measurements through shading, reflection, and heating; and ship-induced flow perturbations, which affect determination of wind speed and direction and thus flux determinations. Additionally, downdrafts around the ship greatly increase the difficulty in making successful radiosonde launches.

Remedies such as stabilized tables and placement of multiple sensors can alleviate some of these concerns, but many issues will remain. Careful calibration of all instruments is, of course, essential. Likewise, it is crucial that redundant measurements are made wherever possible, both to ensure that measurements of quantities of interest can be obtained in case of instrument malfunction or breakage, and as a quality control/validation/comparison of instruments that attempt to measure the same quantities. This is especially important for meteorological measurements, which are most likely to be impacted by ship motion, shading, and other ship artifacts.

The nature of the conditions along transect also imposes sampling requirements. Clouds are often thin and may be small, especially cumulus, which may be only ~100 m or so, placing restrictions on sampling rates as noted above. Marine stratocumulus clouds are optically thin and have low LWPs, often 100 g m 2 or less. The cloud drop effective radius is calculated from the cloud optical depth (which is measured by the Cimel Sunphotometer, [CSPHOT]) and LWP. As both of these quantities are typically quite low, accurate determination of the effective radius requires determination of the cloud optical depth to ±1 or 2 and of LWP to ±~10 g m^{-2}.

Radar measurements are the cornerstones of this campaign; thus, their calibration is key for the entire deployment. To this end, radars should be calibrated after being placed on the ship (to ensure that they are in calibration after being shipped and loaded) and periodically throughout the campaign. The radar sampling strategy must also be customized for shipboard deployment, as noted above. The dominant sampling should be for low clouds, but measurements of cirrus should also be made at regular intervals (e.g., once per minute, or once per kilometer).

Measurements of some of the necessary quantities were not possible. Three-dimensional cloud properties, which would have been provided by scanning radars, would have allowed better understanding of dynamics and cloud structure rather than the soda-straw view given by fixed radars. Such information would also have enabled the possibility of radiative closure, to name but one example. Furthermore, lack of a zenith stabilization on radars means that this straw is moving. Motion corrections for non-zenith-pointing radars, lidars, and optical instruments will introduce additional processing requirements and result in increased noise due to averaging over a range of angles, increasing the difficulty in determining vertical velocities of hydrometeors, for instance.

Individual aerosol particle composition and mixing state are crucial properties that would have yielded information on aerosol sources and additionally would allow direct calculation of other aerosol properties such as cloud activation and hygroscopic properties. These measurements could have been provided with a single-particle mass spectrometer, although this instrument is large and labor-intensive. The aerosol chemical speciation monitor (ACSM), which provides aerosol (as opposed to individual particle) composition would have provided some of this information. Measurements of sea surface current (speed and direction), which are necessary for accurate determination of relative wind speed to calculate fluxes, could have been made with an acoustic Doppler current profiler (ADCP) or a smaller Doppler speed logger. Sea surface temperature and salinity, which are the two most commonly recorded oceanographic quantities and are important for surface fluxes and as tracers of water masses, could have been measured with a thermosalinograph (TSG). Direct measurements of fluxes of momentum, moisture, and latent and sensible heat are key quantities that could be measured by an eddy covariance system, although these are extremely difficult to employ from ships, especially non-research vessels.

5.0 Instruments

The following tables, based on the information in the Construction and Installation Plan for MAGIC (CIP 5-12, 2012), list the instruments to be deployed during MAGIC, their acronyms, and the key quantities they measure. Note that there may be some ambiguity in the categorization of the instruments; e.g., the microwave radiometer (MWR) arguably measures cloud and atmospheric properties. Some of these instruments will not be deployed at the start of the campaign, as noted below the tables.

Table 1. Instruments measuring cloud and precipitation properties.

Instrument Name	Instrument Acronym	Key Quantities Measured
Marine W-band ARM cloud radar (on stable table)	M-WACR	cloud height, structure, and microphysics, precipitation
Ka-band zenith ARM cloud radar (fixed to deck)	KAZR	cloud height, structure, and microphysics, precipitation
Ceilometer	VCEIL	cloud height
High spectral resolution lidar	HSRL[1]	cloud height, structure
Micropulse lidar	MPL	cloud height
Total sky imager	TSI	cloud fraction
Disdrometer		drop size distribution, precipitation rate and amount

Table 2. Instruments measuring aerosol properties.

Instrument Name	Instrument Acronym	Key Quantities Measured
Condensation particle counter	CPC	aerosol particle concentration
Cloud condensation nucleus counter	CCN	cloud condensation nuclei concentration at various supersaturations
Hygroscopic tandem differential mobility analyzer	HTDMA	hygroscopic growth factor, aerosol size distribution
Particle soot absorption photometer	PSAP	aerosol absorption at three wavelengths
Humidified and ambient nephelometers	f(RH)	aerosol light scattering at ambient and various RH
Ultra-high sensitivity aerosol spectrometer	UHSAS	aerosol size distribution
Ozone	O3	ozone concentration

Table 3. Instruments measuring atmospheric and oceanic properties.

Instrument Name	Instrument Acronym	Key Quantities Measured
Balloon-borne sounding system	SONDE	profiles of wind speed and direction, T, RH
Radar wind profiler	RWP[2]	profiles of wind and virtual temperature
Atmospheric sounder spectrometer by Infrared Spectral Technology	ASSISTII	profiles of temperature and water vapor
Infrared thermometer	IRT	sky and sea surface equivalent black body brightness temperature
Infrared sea surface temperature autonomous radiometer	ISAR	sea surface temperature
Microwave radiometer, 2-channel	MWR	column water vapor and liquid
Microwave radiometer, 3-channel	MWR3C	column water vapor and liquid
Psychrometer		RH
Meteorological system on mast	MET	wind speed and direction, T, P, RH, precipitation
Meteorological system on the aerosol observing system (AOS)		wind speed and direction, T, P, RH, precipitation

Table 4. Instruments measuring radiation properties.

Instrument Name	Instrument Acronym	Key Quantities Measured
Portable radiation package	PRP	solar irradiance, hemispheric direct and diffuse fluxes
Shortwave Array Spectroradiometer-Zenith	SASZE[3]	solar radiance as function of wavelength
Precision infrared radiometer	PIR	infrared solar and terrestrial irradiance
Precision spectral pyranometer	PSP	shortwave solar irradiance
Sun pyranometer	SPN	solar irradiance
Cimel sunphotometer	CSPHOT[4]	cloud optical depth
MicroTopsII sunphotometer		aerosol optical depth at several wavelengths

Notes:

1 The HSRL is scheduled to be deployed in May 2013.

2 RWP (Radar Wind Profiler) cannot be operated in port, as it does not operate at an authorized U.S. frequency.

3 The SASZE is scheduled to be deployed in late October 2012.

4 The CSPHOT is scheduled to be deployed in December 2012.

6.0 Logistics

MAGIC principal investigator Ernie Lewis will interface with ARM personnel and/or technicians on board the *Spirit* frequently to ensure that the measurements necessary to achieve the science goals are obtained. It is anticipated that a science observer will ride on most of the legs. Although this observer will not actively participate in measurements except as specifically stipulated beforehand, he/she will have tasks such as making sun photometry measurements with the MicroTops, writing blogs for ARM, making cloud observations for satellite overpasses, etc. His/her presence will be all the more important as there will be no near-real-time access to the data from shore and limited real-time communications with the ship.

Good relations between all MAGIC/ARM personnel aboard the *Spirit* and the captain, chief engineer, and the rest of the *Spirit* crew are essential for all aspects of this deployment. In this regard, MAGIC/ARM personnel must be cognizant of the fact that they are visitors aboard the *Spirit*, where the captain and crew live and work, and as such they must at all times act accordingly. The designated AMF2 lead will be the point of contact between AMF2 and the captain. This does not limit communications; however, if there is any issue aboard the ship, the lead is in charge, and official communication with the ship must go through the lead. Additionally, all efforts should be made to establish good communications with captain and crew. Establishing effective communications with the chief engineer to obtain advanced notice of the daily cleaning of the ship's stacks, which could result in possible soot contamination of optics and other instruments, is especially important, as advanced notice of the timing of such events will allow instruments to be turned off or covered if necessary.

7.0 Relevance to DOE Mission

MAGIC's goals are fully in line with those of the Office of Biological and Environmental Research, which seeks to "*[advance] understanding of the roles of Earth's biogeochemical systems (the atmosphere, land, oceans, sea ice, and subsurface) in determining climate*."

MAGIC will aid the DOE's Atmospheric System Research (ASR) Program in achieving its mission to "*quantify the interactions among aerosols, clouds, precipitation, radiation, dynamics, and thermodynamics to improve fundamental process-level understanding, with the ultimate goal to reduce the uncertainty in global and regional climate simulations and projections*."

MAGIC fits squarely within the mission of the ARM Climate Research Facility, whose primary objective is "*improved scientific understanding of the fundamental physics related to interactions between clouds, aerosols, and radiative feedback processes in the atmosphere*."

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