Goal: Expedite our understanding of key MJO initiation processes and efforts to improve simulation and prediction of the MJO

Approach: Field experiment, numerical modeling, data analysis, and prediction

Sponsors: NOAA, NSF, ONR, DOE, NASA
Motivations of DYNAMO:

(i) Very limited prediction skill for MJO initiation over the Indian Ocean;
(ii) The inability of global models to produce the MJO, which degrades their seasonal to interannual prediction and lessens our confidence in their ability to project future climate.
Overarching proposition: The physical and dynamical processes key to MJO initiation are closely connected to the unique features of the tropical Indian Ocean (e.g., monsoon flows, thermocline ridge, Wyrtki jets) and must be adequately understood using local observations.
Overarching proposition: The physical and dynamical processes key to MJO initiation are closely connected to the unique features of the tropical Indian Ocean (e.g., monsoon flows, thermocline ridge, Wyrtki jets) and must be adequately understood using local observations.

Seychelles-Chagos Thermocline Ridge (SCTR)

1 - 300 m mean temperature (°C)

(Viallard et al. 2008)
Central Problem: Maintenance and transition of different MJO initiation stages

Conceptual Model for MJO initiation:

Pre-onset stage (A): Convectively suppressed; recharging with deepening moist layer, aided by shallow clouds

Onset stage (B): Convectively active, with both shallow and deep (including stratiform) convective clouds; deep moist layer, maintained by low-level moisture supply

Post-onset stage (C): strong surface wind and entrainment cooling; deep convection declining due to low SST

DYNAMO Hypotheses: Three essential factors for MJO initiation

I. Interaction between convection and its environmental moisture
II. Distinct roles of different types of convective clouds at each MJO initiation stage
III. Upper ocean processes and air-sea interaction
DYNAMO Components and Objectives:

Field Campaign: Collect observations of MJO initiation processes that are urgently needed for DYNAMO hypothesis testing through data analysis and modeling.

Analysis: Assist hypothesis testing through exploring empirical relationships among observed variables, evaluating auxiliary data of longer and broader coverage for statistical robustness of the empirical relationships, and preparing data to constrain, validate and evaluate model simulations

Modeling: Quantitatively test the DYNAMO hypotheses, identify deficiencies in numerical models critically responsible for the low prediction skill and poor simulations of MJO initiation, and provide a better physical basis for model improvement

Forecast: Provide real time forecast support to the DYNAMO field campaign, to develop prediction indices for MJO initiation, and to benchmark improvement in MJO prediction.
The DYNAMO Field Campaign:  
the US Participation in CINDY2011  
(Cooperative Indian Ocean Experiment on Intraseasonal Variability in Year 2011)  
October 1, 2011 - March 31, 2012
DYNAMO Air-Sea Interaction Network

10N
Gan
JP/US/CHN
Diego Garcia
US/IND/FRN
10S
65E 75E 85E
CINDY2011/DYNAMO Observing Periods

Long-Term Monitoring (LTM): IndOOS, RAMA

Extended Observing Period (EOP): island-based radar, sounding, and radiation package (SMART-R, AMF2), drifters, enhanced RAMA moorings

Intensive Observing Period (IOP): sounding-radar array, ship-based measurement of air-sea fluxes, atmospheric boundary layer and upper-ocean mixing/turbulence profiles, surface and subsurface moorings, water isotopes, aerosol

SOP*: enhanced sounding

* Special Observing Period
DYNAMO/CINDY2011 (September 2011 – January 2012): atmospheric heating and moistening profiles, cloud and precipitation, upper-ocean mixing and turbulence, air-sea fluxes, water isotopes, aerosol

AMIE (October 2011 – March 2012): radiation, cloud, atmospheric profiles (pairing with DYNAMO SMART-R+AMF2 on Gan for EOP)

HARIMAU (2004 – ): cloud, atmospheric boundary layer

MOMSEI/NSFC-EIC: Two cruises in April–May 2011

PAC$^3$E-SA/7SEAS (2011): aerosol, convection

Enhance and restored sounding operations in the eastern equatorial African countries (pending)
DOE AMF2 Soundings at Gan
8 per day: 1 Oct - 31 March (EOP)

Integrated Sounding Systems (ISSs)
at Diego Garcia and US ship
8 per day: 1 Oct -24 Nov (SOP)
4 per day: 25 Nov - 15 Jan
NCAR Integrated Sounding System (ISS)

- GPS Advanced Upper-Air Sounding System (data to lower stratosphere); Vaisala RS92 sondes
- 915 MHz Doppler clear air wind profiling radar (wind data to ~3 km)
- Radio Acoustic Sounding System (RASS) ($T_v$ to ~1 km)
- Enhanced surface met station (std variables + rad + precip)

Proposal: Two ISSs from NSF Deployment Pool – one at Diego Garcia and one on UNOLS ship
Requested 648 sondes for DG (55 dy @ 8/dy + 52dy@4/dy), 644 for ship (10% for failures)

Additional measurements: GPS column water vapor at both sites; microwave radiometer at Gan
Atmospheric Sounding Network – Science Objectives

- Moistening of troposphere during MJO initiation phase; place observations at Gan supersite in large-scale context
- Vertical profiles of divergence, diabatic heating
- Surface fluxes => close heat and moisture budgets
- Atmospheric boundary-layer properties, structure, and evolution during MJO
- Diurnal cycle of convective and BL processes
- **Field activities:** grad student support with sounding operations; real-time monitoring and display of data; preliminary QC of sounding data
DYNAMO Radar Operation

AMF2 — **Long** (DOE)
- Vertically pointing mm-wavelength
- X-band polarimetric
- Ka-band polarimetric

SMART-R — **Schumacher** (Texas A&M)
- C-band

S-PolKa — **Houze, Medina** (University of Washington)
- S- and K_a-band polarimetric

Ship radars — **Rutledge, Fairall** (CSU) **Revelle**
- Vertically pointing mm-wavelength
- C-band

Aircraft radar — **Jorgensen, Fairall** (NOAA)
- X-band dual-Doppler
- Lower-fuselage C-band
The diversity of radars will allow characterization of the convective cloud ensemble at all stages of the MJO.
CINDY2011/DYNAMO Radar Products

- **3-D reflectivity**
  - Rain maps
  - Convective-stratiform maps
  - Echo top
    - Echo type (e.g., shallow, mid level, and deep convection)
  - Reflectivity PDFs by height
    - Threshold area coverage (e.g., 5, 20, and 40 dBZ)
  - Latent heating
  - Cell size
  - Rain/snow water content

- **3-D polarimetric**
  - Hydrometeor ID
  - Improved rain maps (+-20%)
  - Rain water content
  - Mean diameter

- **Dual-wavelength**
  - Humidity retrievals
  - Total LWC

- **Vertically pointing**
  - Profiles of reflectivity, velocities, and spectral width
  - Cloud boundaries
  - Radiative heating profiles

- **3-D radial velocity**
  - Divergence profiles (VADs)
  - Dual-Doppler/vertical velocity
Radar sites afford virtually unobstructed view of DYNAMO study area to the East.
AMIE-Gan
PI: Chuck Long
ARM/ASR TWP Site Scientist

AMIE Science Steering Committee

Tony DelGenio, Bill Gustafson, Bob Houze, Christian Jacob, Mike Jensen, Richard Johnson, Steve Klein, Ruby Leung, Xaihong Liu, Ed Luke, Peter May, Sally McFarlane, Pat Minnis, Courtney Schumacher, Andy Vogelmann, Yi Wang, Peter Webster, Xiaoqing Wu, Shaohong Xie, Chidong Zhang
AMIE: A 2-prong Campaign

- Will allow study of convective initiation
- “Mature MJO” characteristics
- And propagation/evolution of the MJO
## AMF2 Primary Instrumentation

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Info</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scanning ARM Cloud Radar (SACR)</td>
<td>Active, Scanning X-band (8-12.5 GHz) and Ka-band (35 GHz)</td>
<td>radar reflectivity, radial velocity, and spectrum width</td>
</tr>
<tr>
<td>Millimeter Cloud Radar (MMCR)</td>
<td>Active, Vertically pointing, 94 GHz</td>
<td>Vertical radar reflectivity, doppler spectra</td>
</tr>
<tr>
<td>High Spectral Resolution Lidar</td>
<td>Active, (532 nm)</td>
<td>Cloud and aerosol properties</td>
</tr>
<tr>
<td>Micropulse Lidar (MPL)</td>
<td>Active, (532 nm)</td>
<td>Cloud and aerosol properties</td>
</tr>
<tr>
<td>Boundary Layer Cloud System (Ceilometer, Present Weather System, and Sunphotometer)</td>
<td>eye-safe laser</td>
<td>Cloud, surface meteorology, and aerosol properties</td>
</tr>
<tr>
<td>Microwave Radiometer, 3 Channel (MWR3C)</td>
<td>Passive, K-Band (20-30 GHz), and W-Band (89 GHz)</td>
<td>Vertical or 2-Dimensional profiles of precipitable water vapor and liquid water path</td>
</tr>
<tr>
<td>Solar Spectrometer (SWS)</td>
<td>Passive, (300 to 2000 nm)</td>
<td>Solar spectral radiance and irradiance</td>
</tr>
<tr>
<td>Radar Wind Profiler (RWP)</td>
<td>Active, (new 1290 MHz, or existing 915Mhz)</td>
<td>Profiles of windspeed and direction (u,v,w)</td>
</tr>
<tr>
<td>Digicora Radiosonde System</td>
<td>Sondes</td>
<td>Atmospheric profiles of temperature, water vapor, horizontal winds, and pressure</td>
</tr>
<tr>
<td>Meteorology (MET)</td>
<td></td>
<td>Temperature, relative humidity, wind speed and direction, rainfall, and barometric pressure</td>
</tr>
<tr>
<td>Total Sky Imager (TSI)</td>
<td></td>
<td>Daylight sky images, fractional sky cover</td>
</tr>
<tr>
<td>Atmospheric Emitted Radiation Interferometer (AERI)</td>
<td>Passive, 3-19.2 microns</td>
<td>Vertical spectral LW radiance</td>
</tr>
<tr>
<td>Downwelling Radiation (SKYRAD)</td>
<td>Passive, broadband SW and LW</td>
<td>SW, LW, SW Diffuse and Direct irradiance, infrared sky temperature</td>
</tr>
<tr>
<td>Upwelling Radiation (GNDRAD)</td>
<td>Passive, broadband SW and LW</td>
<td>SW and LW irradiance, infrared skin temperature</td>
</tr>
<tr>
<td>Multifilter Rotating Shadowband Radiometer (MFRSR)</td>
<td>Passive, 415, 500, 615, 673, 870, and 940 nm</td>
<td>Aerosol optical depth, cloud optical depth, fractional sky cover</td>
</tr>
<tr>
<td>Eddy Correlation (ECOR) system</td>
<td>Passive, sonic anemometer and assoc. Inst.</td>
<td>surface turbulent fluxes of momentum, sensible heat, latent heat, and carbon dioxide.</td>
</tr>
</tbody>
</table>
## AMF2 Aerosol Instrumentation

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humidigraph (Scanning Relative Humidity with 3 single wavelength nephelometers)</td>
<td>Aerosol scattering coefficient as a function of relative humidity</td>
</tr>
<tr>
<td>Cloud Condensation Nuclei (CCN)</td>
<td>Condensation nuclei spectra</td>
</tr>
<tr>
<td>Particle Soot Absorption Photometer (PSAP), 3 Wavelength</td>
<td>Aerosol absorption coefficient</td>
</tr>
<tr>
<td>Nephelometer, 3 Wavelength</td>
<td>Aerosol scattering coefficient</td>
</tr>
<tr>
<td>Condensation Particle Counter (CPC)</td>
<td>Condensation particle concentration, 10 nm to &gt;3000 nm</td>
</tr>
<tr>
<td>Hygroscopic Tandem Differential Mobility Analyzer (HTDMA)</td>
<td>Aerosol growth factor as a function of humidity</td>
</tr>
<tr>
<td>Ozone Monitor</td>
<td>Ozone concentration</td>
</tr>
</tbody>
</table>
**Project Timeline**

<table>
<thead>
<tr>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
</tr>
</thead>
</table>

**EOP**

- AMIE-Gan (AMF2), SMART-R, AMIE-Manus, Darwin

**IOP**

- S-PolKa, RV Revelle, RV Sagar-Kenya and RV Southern Surveyor (plus EOP observations)

**SOP**

- RV Mirai (plus IOP and EOP observations)

AMIE-Gan and AMIE-Manus will be launching 8/day sondes for the entire EOP
DYNAMO Ship Operation
R/V Revelle Atmospheric Sensors

- Fluxes and Near-Surface Meteorology – Uconn (Edson), ESRL/PSD (Fairall), OSU (deSzoeko)
- C-band Radar – CSU (Rutledge)
- W-band Radar – ESRL/PSD (Fairall)
- Microwave Radiometer – U Miami (Zuidema)
- Doppler Lidar – ESRL/CSD (Brewer)
- Water isotopic composition – CSU (Noone)
- Wind Profiling Radar – NCAR (Brown)
- Balloon Sounding System - NCAR (Brown)
- Surface Waves – Columbia U. (Zappa)
• Direct Covariance Flux System
  – 1–2 DCFS with Sonic & MotionPak
  – Infrared Hygrometers
    • Licor 7500 Open Path
    • Licor 7200 enclosed “Open” Path
  – Downwelling Longwave Pyrgeometer
  – Downwelling Shortwave Pyranometer
  – RH/T/P Sensors
  – Rain Gauge
  – IR SST (if necessary)
Aerosol Measurements During DYNAMO
Shipboard measurements of the physical, chemical, optical, and cloud nucleating properties of aerosols to elucidate the processes and cause-and-effect relationships between aerosols, cloud physics, and precipitation.

Time series of aerosol parameters and derived empirical relationships that can be used by cloud-resolving and GCMs.
ESRL/PSD W-Band Stabilized Doppler Cloud Radar
94-GHz, 25-m vertical resolution, 0.3 s dwell

Radar and Stabilizer in seatainer during VOCALS 2008

Samples of 1-hr time-ht cross sections during various stages of growing, mature, and decaying trade BL convection
C-Band & W-Band in Weak Precipitation

PHOTO IN DIRECTION OF RHI
HRDL seatainer mounted on the Fantail of the same ship during TEXAQS study in 2006. The outriggers hold GPS antennae associated with the lidar’s motion compensation/stabilization system.

Twelve hour archive images, automatically loaded to the web in real time, of profiles measured by HRDL during the Second Texas Air Quality Study in 2006. The top panel is horizontal wind speed and direction, the middle plot is aerosol backscatter intensity, and the bottom plot is vertical velocity variance ($w'^2$).
Combined W-Band & Lidar Statistics

Full BL properties by linking subcloud (lidar) and incloud (radar) returns

24-hr time-height cross section of backscatter (left panel) and vertical velocity variance (right panel) from stratocumulus-topped BL during VOCALS 2008. Cloud top is 1.3-1.5 km (top of radar returns); cloud base is the solid line. Radar variables above cloud base and lidar below cloud base. Turbulence is suppressed during the day by solar heating in the cloud.
shipboard profiling 24h ops / fixed station

subsurface flux measurements coordinated with
surface fluxes
Doppler radar

*Chameleon* turbulence profiler

multiple high-res modern ADCPs sampled rapidly
Hull 50 kHz
140 kHz
Over-the-side 150 kHz
DYNAMO Mooring Operation

DYNAMO moorings
subsurface expression
$\chi$ pods on DYNAMO / RAMA moorings

- moored subsurface flux measurement
- analogous to a surface flux tower

Moum & Nash 2009
R/V Roger Revelle Schedule

Installation  23 Aug – 3
Deployment    30 Aug – 25 Sep
Moum Leg 1   28 Sep – 30 Oct
Pinkel Leg 2  03 Nov – 23 Nov
Moum Leg 3   27 Nov – 03 Jan
Recovery     09 Jan – 03 Feb

R/V Revelle Tracks / DYNAMO

R/V Revelle Timeline ver.1

- all moorings in place
- mooring deployment
- mooring recovery
- installation
- Darwin
- NSF
- NSF / NOAA
- ONR / NSF
- ONR
- NSF

Agency Request → NSF / NOAA
Ch. Scientist → Lien

Sep  Oct  Nov  Dec  Jan 2012  Feb
R/V Roger Revelle Schedule

Installation 23 Aug – 3 Sep
Deployment 30 Aug – 25 Sep
Moum Leg 1 28 Sep – 30 Oct
Pinkel Leg 3 12 Dec – 8 Jan
Recovery 09 Jan – 3 Feb
DYNAMO Aircraft Operation

NOAA WP-3D

AIRCRAFT CHARACTERISTICS
Crew: 7–8; Scientists: up to 12
Operational Airspeed: 170–250 KIAS [210 KIAS]
Max Take off Weight: 135,000 lbs.
Service Ceiling: 27,000 Feet
Low Altitude Range: 2,500 Nautical Miles
(4,600 Km) [9.5 hours]
High Altitude Range: 3,800 Nautical Miles
(7,000 km) [11.5 hours]
5–6 weeks field phase in Nov–Dec 2011
Flight Pattern Modules for Air–Sea Processes Study

Figure 2: Flight patterns: (a) Cross-wind vertical stack, (b) cross-section slant path and (c) surface flux mapping.
Post-COARE instruments: SFMR, GPS dropsondes, turbulence, etc.
Post-COARE instruments: AXCTDs, AXCPs

<table>
<thead>
<tr>
<th>PROBE SPECIFICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROBE</td>
</tr>
<tr>
<td>AXCTD</td>
</tr>
<tr>
<td>AXSV</td>
</tr>
<tr>
<td>AXCP</td>
</tr>
</tbody>
</table>
Fig. 3. “Survey” module to sample the larger scale aspects of the convective systems. This will be done in all class systems. Leg lengths will be adjusted based on the extent of the precipitation shield or 208 K contour on IR satellite imagery. (Chen et al. NOAA proposal)
Fig. 2. Flight pattern module for the documentation of convective features. (Chen et al. NOAA Proposal)
Dropsonde Deployment Strategy

(a) Flight track

(b) Initial flight track

Reverse flight track

4 Km or 6 Km

6 Km
DYNAMO Modeling

- **DYNAMO Modeling Group** (Co-Chair, Eric Maloney, CSU, and Augustin Vintzileos, NCEP): members from Universities, NCAR, NCEP, NASA/GMAO, GFDL, NRL/MTR
- **Model Hierarchy**: single column, large-eddy simulation (LES), regional, tropical and global cloud-system resolving, global GCMs
- **General Goals**: Improve the convective (shallow & deep cumulus) and microphysics parameterizations
- **Field Experimental Design**: guided by modeling activities
- **Targeted Model Evaluation**: using specific field observations
- **Hypothesis Testing**: using models constrained and validated by DYNAMO field observations
- **Numerical Experiments**: to be organized with a broader international participation under the protocols of CLIVAR AAMP & IOP, MJOTF, YOTC.
Ocean Modeling Group (1-D mixed layer models, ocean circulation models, OGCM, coupled atmosphere-ocean models) - to be organized and strengthened between DYNAMO, ONR, and CINDY ocean modeling groups

- **Key Process:** upper ocean heat, energy budget, diurnal cycle

- **Hypothesis Testing:**
  1. Turbulent heat flux is a key component of the surface mixed layer heat budget in the Central Indian Ocean
  2. Effects of the barrier layer, magnitudes and scales, can modulate the SST and therefore the MJO initiation and evolution
  3. Wyrtki jet can lead to the formation of barrier layer
  4. Seychelles–Chagos thermocline ridge is strongly responsive to the MJO
  5. Diurnal variability of SST, mixed layer, turbulent
DYNAMO Data Analysis

- Field observation analysis
- Preparation for model forcing, constraint, and validation
- Special DYNAMO reanalysis products (NCEP, JAMSTEC, ECMWF)
- Field observation comparisons to:

  => Satellite data
      - moisture (soundings, S-Polka vs. AIRES, MEGHA-TROPIQUES)
      - diabatic heating (soundings, radars vs. TRMM)
      - cloud population statistics (radars vs. CloudSat, MEGHA-TROPIQUES)
      - SST (ship and mooring vs. TMI)

  => Recent reanalysis products: CFS-R, MERRA, ERA-interim
  => Weather prediction products: NCEP, ECMWF, JMA ...
DYNAMO Forecast

- High-resolution NWP products (NCEP, ECMWF, BOM, JMA) will provide real-time field support for radar and aircraft operations.
- Multi-model ensemble prediction skill for MJO initiation will be evaluated (NCEP/CPC).
- An objective MJO initiation index will be developed (NCEP, universities).
- Real-time forecast of the MJO and its global impact (NCEP/CPC) connects DYNAMO research outcome directly to societal benefit.
DYNAMO Program Structure

DYNAMO Science Steering Committee
(16 members from universities, federal laboratories, and operations centers)

DYNAMO Project Office

DYNAMO student participation

DYNAMO Working Groups (PI Teams):
- Modeling
- Radar observations
- Ship observations
- Aircraft observations

Field Campaign, Modeling, Model-Observation Integration, Prediction Experiments

DYNAMO Data Center

CINDY Data Center
Time Table

DYNAMO:

- White paper (summer 2008)
- US CLIVAR briefing (summers 2008, 2009)
- Planning workshops (April 2009, July 2010)
- First site visit (February 2010)
- NSF overview documents review (spring 2010)
- NSF Facility Request (summer 2010)
- DOE facility proposal funded (September 2010)
- ONR science team meeting (October 2010)
- NSF/NOAA proposal review (fall 2010)
- NSF/NOAA proposal decision (December 2010)
- Operations workshop (spring 2011)
- Field preparation (January - September 2011)
- Field campaign starts (October 1, 2011)