Global Monsoons: Four Decades of Field Campaigns

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Field Campaigns Investigating Monsoon Weather and Climate

- WMONEX (1978)
- TAMEX (1987)
- SCSMEX (1998)
- NAME (2004)
- AMMA (2006)
- TIMREX/SOWMEX (2008)
- SCMREX (2013-2018)
- PISTON II/CAMPEx (2019)
- PRECIPTAHOPE/
- T-PARCII

*AUSTRALIAN MONSOON EXPERIMENT (AMEX 1986-87)
In August 1966, NCAR hosted a meeting of university scientists and agency representatives (NCAR, ESSA, NASA, NAS) to plan an integrated program of tropical experiments over the next 5-10 years. **Chairs:** Charney, Ramage, LaSeur

- Line Islands Experiment (1967-68)
- BOMEX (1969)
- ATEX (1969)
- GATE (1974)
- Winter MONEX (1978)
- Summer MONEX (1979)
South China Sea area past field campaigns...
Other Monsoon-Related Field Campaigns

- VASCO-CIRENE 2007
- MISMO 2006
- HARIMAU 2006
- TWP-ICE 2006
- AMEX 1986-87
- NAME 2004
Field Campaigns Investigating Monsoon Weather and Climate

- WMONEX (1978)

Participating countries: Malaysia, Indonesia, Thailand, Philippines, Hong Kong, Japan, Singapore, Australia, People’s Republic of China, U.S.S.R., U.S.A.

Winter MONEX
December 1978

Ops Center
Kuala Lumpur

MIT radar

NOAA P-3, Electra

Ship soundings

MIDNIGHT

Diurnal Cycle of Convection

Houze et al. (1981)

Repeatable diurnal cycle of convection developing off north coast of Borneo at night, moving offshore, and growing into expansive MCS, then decaying anvil.

(Johnson and Houze 1987)
Participating countries: Malaysia, Indonesia, Thailand, Philippines, Hong Kong, Japan, Saudi Arabia, Singapore, Australia, People's Republic of China, U.S.S.R., U.S.A.

Winter MONEX  
December 1978

Radiative Effects of Mesoscale Anvil Clouds

Radiative effects of thin and thick anvil clouds cannot be neglected in relation to latent heating effects

Webster and Stephens (1980)
Participating countries: Malaysia, Indonesia, Thailand, Philippines, Hong Kong, Japan, Saudi Arabia, Singapore, Australia, People's Republic of China, U.S.S.R., U.S.A

Winter MONEX December 1978

Structure of Borneo MCSs Based on Soviet Soundings

Cool anomalies

Warm anomalies

Properties of MCSs similar to those observed earlier in the tropics (e.g., Line Islands, GATE)

Ops Center Kuala Lumpur

(Johnson and Houze 1987)

(Johnson and Kriete 1982)
Field Campaigns Investigating Monsoon Weather and Climate
The Taiwan Area Mesoscale Experiment (TAMEX, May-June 1987)

Study of heavy rainfall
- Meiyu front
- Mesoscale convective systems
- Orographic effects
- Local circulations

Doppler radars, soundings, surface stations, NOAA P-3 aircraft

(Trier et al. 1997)
The Taiwan Area Mesoscale Experiment
(TAMEX, May-June 1987)

Study of heavy rainfall associated with
- Meiyu front
- Mesoscale convective systems
- Orographic effects
- Local circulations

TAMEX Planning Meeting, Boulder 1986
TAMEX observations of convection
(Chen et al. 1989; Trier et al. 1990;
Ray et al. 1991; Lin et al. 1992; Chen
and Chou 1993; Chen and Li 1995; Li
et al. 1997; others)

Ø “Meiyu front”: shallow (~1–2 km
deep); T contrast ~5 C near N.
Ø Rainbands aligned along front,
convection on warm side
Ø Low-level jet in advance of front,
assists convective development
Ø Topography aids low-level
convergence and convection
Ø Back-building contributes to heavy
rainfall

Weather radars
TAMEX Radar observations along “Meiyu” front (Trier et al. 1990; Lin et al. 1990, 1992; Wang et al. 1990; Chen and Chou 1993; Chen and Li 1995; Li et al. 1997; others)

(Trier et al. 1997)
TAMEX Radar observations of convection along “Meiyu” front (Trier et al. 1990; Lin et al. 1990, 1992; Wang et al. 1990; Chen and Chou 1993; Chen and Li 1995; Li et al. 1997; others)

Back-building convection along Mei-Yu front

(Li, Chen and Lee 1997)
Barrier jets frequently associated with heavy rainfall; orographic effects (Chen et al. 1991; Akaeda et al. 1995; Chen and Chen 1995; Chen et al. 1994; Chen et al. 1997; Li and Chen 1998)
Field Campaigns Investigating Monsoon Weather and Climate
South China Sea Monsoon Experiment (SCSMEX) – May-June 1998

Study of key processes associated with onset and evolution of SE Asia summer monsoon

People’s Republic of China, Taiwan, U.S.A., Australia, Hong Kong, Philippines

Participating students from CSU: Jim Kossin, Matt Garcia, Adam Kankiewicz, Kathy Straub, Christine Kaufman

(SCSMEX review: Lau et al. 2000, BAMS)
South China Sea Monsoon Experiment (SCSMEX) – May-June 1998

SCSMEX Sounding Network and SST field (May-June 1998)
SCSMEX 6-hour Radar Animation

BMRC C-POL Radar

Linear MCS archetypes

- **TS**: Trailing Stratiform
- **LS**: Leading Stratiform
- **PS**: Parallel Stratiform

(Initiation → Development → Maturity)

5 June 1998

Trailing Stratiform

BMRC C-POL RADAR

(Dongsha - SCSMEX CPOL RADAR REFLECTIVITY)

Hong Kong

(Parker and Johnson 2000)

(Johnson, Aves, Ciesielski, Keenan 2005)
SCSMEX 4-hour Radar Animation

18 May 1998

BMRC C-POL Radar

Leading Stratiform

Linear MCS archetypes

- **TS** (Trailing Stratiform)
- **LS** (Leading Stratiform)
- **PS** (Parallel Stratiform)

(Parker and Johnson 2000)
Heavy rainfall

SCSMEX 6-hour Radar Animation

8 June 1998

Parallel Stratiform, Back-building

BMRC C-POL Radar

Linear MCS archetypes

Initiation  Development  Maturity

TS  Trailing Stratiform

LS  Leading Stratiform

PS  Parallel Stratiform

(Parker and Johnson 2000)

(Schumacher and Johnson 2005)
North American Monsoon Experiment (NAME) July-August 2004

- Goal: To investigate the sources and limits of predictability of the North American Monsoon

- Moist convection
- Diurnal cycle
- Land/atmosphere coupling
- Easterly waves
- Upper-level inverted troughs (TUTT disturbances)
- Gulf of California surges
- Tropical cyclones
- Madden-Julian Oscillation (MJO)

(Higgins et al. 2006, BAMS)

CSU Student Participants:
Pete Rogers, Angela Rowe
• **Enhanced sounding network:** up to 6/day launches during 18 IOPs days

• **To study Gulf Surges:** three NCAR ISS systems deployed along Gulf of California: Puerto Peñasco, Bahia Kino, Los Mochis

Radar data from S-Pol and other radars documented diurnal cycle of convection over Sierra Madre Occidental
Diurnal Cycle of Convection over the Sierra Madre Occidental

- Early morning shallow clouds over peaks, light rain
- Clouds move downslope, deepen, and organize in afternoon (Lang et al. 2007; Rowe et al. 2008)
- Most intense rainfall, deepest warm-cloud depths over coastal plain (Gochis et al. 2007; Rowe et al. 2008)
- Slightly delayed diurnal convective peak: morning clouds, west-facing slopes (Johnson et al. 2010)
Gulf of California surge

12-14 July
- Surge moves up Gulf at ~17-22 m s\(^{-1}\)
- Surge stronger and shallower in northern Gulf
- Surge amplified by nocturnal LLJ
Field Campaigns Investigating Monsoon Weather and Climate

- WMONEX
- TAMEX
- SCSMEX
- NAME-AMMA
AMMA – To improve our understanding of the West African Monsoon and its physical, chemical and biological environment.
Coupling between convection and easterly waves
Field Campaigns Investigating Monsoon Weather and Climate

- WMONEX
- TAMEX
- SCSMEX
- NAME
- AMMA
- TIMREX/SOWMEX

1980 - 1990 - 2000 - 2010 - 2020
Scientific Objectives

- Terrain effect on the flow and MCSs
- MCS dynamics, microphysics, and predictability
- Mesoscale data assimilation/QPF
- Convective initiation/diurnal cycle/boundary layer processes

Participants

- Field phase: US-Taiwan
- Post-field phase activities/workshops: Korea, Japan, Viet Nam, PRC

Participating student from CSU: Angela Rowe
Observations of shallow fronts (Davis et al. 2012)

- Despite shallowness and weak $T$ gradient, impact on convection is significant due to moist, unstable conditions
- $T$ contrast reinforced by cool downdrafts over land
- Analogous to coastal fronts at higher latitudes

990 hPa wind, $T_v$ at 06Z on 5 June 2008
Extreme rainfall 14-16 June 2008 (Xu et al. 2012)

- Convective cell triggering by low-level jet impinging on shallow cold pool
- Cold pool reinforced by continuous precipitation
- Cold pool trapped by terrain
- Virtual extension of island barrier to the southwest

(Xu et al. 2012)
**Diurnal Cycle of Convection during TiMREX**

**Undisturbed**

- **Early Morning**
  - Morning rainfall offshore, afternoon maxima on coastal plain

- **Afternoon**
  - Dominant rainfall on at higher elevations over CMR in afternoon

*(Ruppert, Johnson & Rowe 2013)*
Dynamic Lifting on Downshear Side of Positive Potential Vorticity Anomaly

\[ P = - (\zeta + f) \frac{\partial \theta}{\partial p} \]

Shear vector

Background PV-relative flow

\( \theta_1 \)
\( \theta_2 \)
\( \theta_3 \)

100 km

\( +p \)

Isentropic upglide

Heavy rain on downshear side

(figure from Trier, Davis, and Tuttle 2000, MWR)
Mesoscale Convective Vortex (MCV) during TiMREX

4-5 June 2008 Heavy Rainfall
TiMREX/SoWMEX

(Lai, Davis, and Jou 2011, MWR)

Heavy rain over southern Taiwan downshear of vortex center, aided by moist southwesterly flow
• Warm air flowing over cool water
• Leads to weak surface fluxes, stable boundary layer, low-level convergence

SST-gradient-driven convergence enhanced rainfall along southwest coast of Taiwan by ~20% during 13-18 June (Toy and Johnson 2014)
Field Campaigns Investigating Monsoon Weather and Climate
South China Monsoon Rainfall Experiment (SCMREX, 2013-18)

A program for improving heavy rainfall forecasts over southern China during the presummer rainy season

Luo et al. (2016, BAMS)

Collaborators: PRC, USA, UK, Taiwan
Field Campaigns Investigating Monsoon Weather and Climate
How does the BSISO influence the atmosphere (convection, diurnal cycle) and upper ocean over SCS

How does convection/diurnal cycle/upper ocean feed back to influence the BSISO

Operations moved to Philippine Sea
PROPAGATION OF INTRA-SEASONAL TROPICAL OSCILLATIONS (PISTON) (AUG-OCT 2018)

Science highlights
- Tropical cyclone “tails”
- Upper-ocean response to TC passage

Participating countries: US, Taiwan (SCSTIMEX), Philippines, Japan
Field Campaigns Investigating Monsoon Weather and Climate

- WMONEX
- TAMEX
- SCSMEX
- NAME
- AMMA
- TIMREX/SOWMEX
- SCMREX
- PISTON
- PISTON II/CAMPEX (2019)

How does the BSISO influence the atmosphere (convection, diurnal cycle) and upper ocean over SCS?

How does convection/diurnal cycle/upper ocean feed back to influence the BSISO?

Operations again moved to Philippine Sea

- Air-sea interaction
- Ocean processes – response to TC forcing, diurnal cycle
- SST variability (P-3 missions)
- Shallow cumulus, MCSs, cold pools
- Aerosol and cloud microphysics (NASA mission)

Figure 2 – Sally Ride ship track PISTON 2019
Field Campaigns Investigating Monsoon Weather and Climate
Prediction of Rainfall Extremes
Campaign In the Pacific (PRECIP) 2022 (?)

• PRECIP has been proposed for 25 May – 10 August 2022 to observe Meiyu front, MCSs, diurnal convection, and typhoons near Taiwan
• Part of an international effort to study extreme rainfall
  • Taiwan TAHOPE (Taiwan-Area Heavy rain Observation and Prediction)
  • Japan T-PARCII (Tropical cyclones-Pacific Asian Research Campaign for Improvement of Intensity estimations/forecasts)
  • NOAA IFEX-WP (Intensity Forecast Experiment –Western Pacific)
Summary

- **Forty years of international monsoon field campaigns:** monsoon dynamics, investigations of mechanisms contributing to heavy rainfall
- **Observing systems:** increasing sophistication and density, yielding new insights into a wide range of phenomena
- **Extreme rainfall mechanisms, new understanding:** Meiyu front, MCS organization, orographic effects, MCVs, cold pools, diurnal cycle, SST effects
- **Campaign results:** have contributed to improvements in modeling, physical parameterizations, prediction
Lessons

Science

- **SCS region**: Moist, unstable conditions and weak CIN over northern SCS during onset of summer monsoon: convection is readily initiated by Meiyu front, cold pools, orography, flow blocking, SST gradients
- **North American monsoon**: Gulf surges influenced by diurnal cycle of SMO convection and TCs
- **Extreme rainfall** is often a result of a complex interplay among above processes
- **MCS organization leading to extreme rainfall**: many aspects in monsoon regions similar to that observed elsewhere in the tropics and in the midlatitudes
- **Scientific results**: unexpected findings are the norm
Lessons

Logistics

- **Field planning:** be prepared to adjust for last-minute changes
- **Execution of field phase:** doesn’t always go as planned
- **Weather:** doesn’t always cooperate, be flexible
- **Observations, modeling, data assimilation:** keep closely coupled during all phases
- **Collaborations:** Maximize international partnerships
- **Encourage program managers to come to field**
- **Students and young scientists:** always involve in all phases
END

(part of FGGE – First GARP Global Experiment)

December 1978

Joach Kuettner
SCSMEX sounding-derived fields used as a basis for TRMM/GPM latent heating algorithms (Tao et al., Shige et al.)

Divergence, omega, $Q_1$, $Q_2$

(Johnson and Ciesielski 2002)
The Cloud, Aerosol and Monsoon Processes Philippines Experiment (CAMP$^2$Ex) (August-September 2019)

An investigation of the coupling between clouds and aerosols

- Aerosol and cloud microphysics
- Cloud and Aerosol Radiation
- Aerosol and cloud meteorology
Winter Monsoon Experiment (WMONEX)
December 1978

Joach Kuettner
Understanding the microphysical drivers of model biases for SC heavy rainfall \((Kalli\ Furtado,\ Met\ Office,\ UK)\)
\((Furtado\ et\ al.,\ 2018,\ JGR)\)

- Rain # concentration determines rainfall & low-level reflectivity biases
- TOA biases are determined by:
  - cloud fraction diagnosis (low clouds)
  - assumption of ice crystal fallspeed (high clouds)
- 1M could be tuned to produce comparable results of 2M

May 2016

![Radar](courtesy\ Yali\ Luo)

Cloud water path

<table>
<thead>
<tr>
<th>MODIS</th>
<th>2M CS</th>
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<td>C=0 or 1, (R_h_{\text{crit}})=1; 0&lt;(C_{\text{liq}})&lt;1, (R_h_{\text{crit}})&lt;1</td>
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![Temperature](temperature_graph)

![Concentration](concentration_graph)
Field Campaigns in East Asia/SCS Area

- WMONEX (1978)
- TAMEX (1987)
- SCSMEX (1998)
- TIMREX/SOWMEX (2008)
- SCMREX (2013-2018)
- PISTON II/CAMP2EX PRECIP/TAHOPE
Fig. 1. Rainfall totals (mm) for 7–13 Dec 2004. Northeast monsoon flow impinging on the coastal mountains of Malaysia triggered heavy rains—the worst in more than 40 years—that killed at least 11 people and forced the evacuation of more than 10,000. Image from TRMM-based Multi-Satellite Precipitation Analysis of the National Aeronautics and Space Administration Goddard Space Flight Center.

(Johnson and Chang 2007)