Emerging results from the 2016 INCOMPASS field campaign of the Indian monsoon

AG Turner, GS Bhat and many others
INCOMPASS is one of 3 collaborative projects built around a ground, ship and airborne campaign

- **BoBBLE** Bay of Bengal Boundary Layer Experiment [Prof. PN Vinayachandran (IISc) & Prof. Adrian Matthews (UEA)]
- **SWAAMI** South West Asian Aerosol Monsoon Interactions [Dr S Suresh Babu (ISRO) & Prof. Hugh Coe (Manchester)]
- **INCOMPASS** [Prof. GS Bhat (IISc) & Dr Andy Turner (Reading)]

Joint UK-India programme to develop better understanding of processes driving predictability of the South Asian monsoon

Combined £8M funding from UK NERC, Newton fund, Indian Ministry of Earth Sciences (MoES; via the Monsoon Mission) & Met Office
- Interaction of Convective Organisation with Monsoon Precipitation, Atmosphere, Surface & Sea

- Better understanding of interactions between (land) surface, boundary layer, convection, the large-scale environment & monsoon variability on range of scales

How?

- Combine airborne & ground field observations with nested atmospheric and land-surface modelling at a range of resolutions, including a tests at ~300m

Ultimate, long-term goal:

- To improve skill of monsoon rainfall prediction in weather & climate models
Bias development in the MetUM (or many others...)

- Rapid growth of model errors suggests that it is a direct impact of parametrizations and not due to a non-linear feedback process operating on longer time-scales.

Slide courtesy Gill Martin, Met Office (Martin et al., 2010; doi:10.1175/2010JCLI3541.1)
INCOMPASS partner institutes
Personnel

- Indian Inst. Science (IISc, Bangalore): GS Bhat, M Sekhar +…
- NCMRWF: Rajagopal, Ashis Mitra, Jayakumar...
- IMD: Ranju Madan + many others
- IIT Bhubaneswar: Sandeep Pattnaik +…
- IIT Kanpur: S Tripathi + many others
- NAL: Mrudula + students
- ISRO: partnership with Bimal Bhattacharya
- Reading: Andy Turner + Arathy Menon + Kieran Hunt + Karl J-C
- Met Office: Gill Martin, Stu Webster, Sean Milton +…
- Leeds: Doug Parker, John Marsham, Cathryn Birch, Jennifer Fletcher + Peter Willetts, Lucy Recchcia, Luis Garcia-Carreras…
- CEH: Chris Taylor, Jon Evans, Danijel Belusic, Ross Morrison +…
THE ATMOSPHERIC RESEARCH AIRCRAFT & FLIGHT STRATEGY
The FAAM Atmospheric Research Aircraft

- Owned by the UK Natural Environment Research Council (see www.faam.ac.uk)
- Modified BAe-146 jet with seats for around 18 scientists plus flight crew
- Range ~4.5 hours flying time (India*)
- In-situ temperature & humidity
- Remote sensing lidar & radar
- Turbulent fluxes
- Cloud
- Chemistry
  - (SWAAMI)
Overall INCOMPASS flight strategy

Spatio-temporal variations in the monsoon:

① To sample spatial contrasts across northern India in the pre-monsoon and as the onset progresses

② To sample contrasts across southern India in the mature monsoon

Based on APHRODITE data 1951-2007
Distribution of 22 flights performed June/July 2016; 2 airport bases

Pre-planned and responsive flights

1. Repeated sampling of expected contrasts at various times in the monsoon

2. Flights-of-opportunity (e.g. for monsoon depression, or for dust / aerosol as per weather conditions)

Image courtesy Gill Martin/Justin Langridge, Met Office
GROUND COMPONENTS OF THE FIELD CAMPAIGN
Flux towers

Eddy covariance flux towers installed by INCOMPASS:

- N1=IIT Kanpur
- N2=Kabini/Berambadi (Karnataka)
- N3=Dharwad (Karnataka)
- U0=IIT Bhubaneswar (Odisha)
- U1=Nawagam/Anand, semi-arid site (Gujarat)
- U2=Jodphur/Jaisalmer, arid site (Rajasthan)
- U3=Samastipur (Bihar)
Example flux measurements

Partitioning between SH and LH fluxes at **Dharwad** through 2016 (Courtesy: Ross Morrison, CEH)
Measurements to continue for many years to come

GS Bhat erecting Bhubaneswar tower, NE India coast

Kanpur site

Dharwad site

Berambadi site
IIT-Kanpur supersite (~85km to Lucknow)

Flux tower: permanent installation; surface flux data sent via mobile network to UK
Lidar ceilometer: permanent installation; test data have successfully tracked cloud base
Microwave radiometer: permanent
Radiosonde receiving station: intensive observations during July capturing diurnal cycle

Further instruments near “entrance” to monsoon trough, at IIT-Bhubaneswar: Flux tower, MW radiometer & vertical precipitation radar
Example emerging finding from aircraft survey

**FLIGHT CASE STUDY:**

**SOIL MOISTURE & STORM INITIATION**

Emma Barton *et al.* (Geophys. Res. Letts., to be submitted)
Analysis of flight B968 west of Lucknow
30/06/16

Google Earth image and flight path
(Low-level run highlighted)

Average air pressure ~ 950hPa
Average height above ground (radar alt.) ~ 191m

Source: Emma Barton & Chris Taylor CEH, UK
In-situ aircraft data from low-level transect

Significant horizontal temperature gradient \( \Delta T_{\text{max}} \approx 5^\circ \text{C} \)

Strong variations in along- and cross-track winds

Distance along low-level track →

Courtesy: Emma Barton/Chris Taylor CEH
Potential temperature & wind at flight level

Initiation points on flight track (X1 and X2) are in the area of the strongest convergence.

Large-domain comparison with ERA-Interim

Courtesy: Emma Barton/Chris Taylor CEH
Polarization ratio derived from GPM 10.7 GHz brightness temperatures (Overpass approx. 03:20 UTC)

"Wetter" areas correlated with cooler air temperatures

Steep gradients in air temperature correlated with "Wet/Dry" transitions

→ These correspond to the strong convergence along the flightpath shown earlier

drier soils

…with potential temperature (K) along flight track

wetter soils

Satellite-derived soil moisture (proxy)

Courtesy: Emma Barton/Chris Taylor CEH
Development of post-flight clouds (afternoon)

$X\# = \text{initiation of deep convention (when cloud top brightness temperature drops below -30}^{\circ}\text{C)}$

Courtesy: Emma Barton/Chris Taylor CEH
INCOMPASS is based around a ~100-hour aircraft campaign during the 2016 Indian monsoon

Addition of:

- 8 semi-permanent eddy-covariance flux towers
- Enhanced RS launches during the campaign
- Lidar ceilometer (at Kanpur supersite)
- Micro rain radar (at Bhubaneswar supersite)
- 3 MW radiometers, 5 disdrometers

Nested modelling work at 4km resolution and above

- Key case studies to be developed on July 2016 depression among others

Already key demonstrations of land-atmosphere interactions in convective storm initiation
Thank you!

a.g.turner@reading.ac.uk
@agturnermonsoon

- Most data will be publicly available this summer
- A special issue of Quarterly Journal of the Royal Meteorological Society dedicated to INCOMPASS is expected in 2019
AMMA field studies
- Remote sensing
- Theory and process studies
- CRM: LAM: GCM

HAPEX-Sahel (1992): Taylor and Lebel
Taylor and Clark
Taylor and Ellis

AMMA research flights: Soil moisture feedbacks exist and are significant
Taylor et al. 2007, 2010
Dixon et al. 2012

Composition controlled by mesoscale surface:
Taylor/Stewart;
Crumeyolle et al.;
Ferreira et al.

Vegetation forcing of PBL and cloud demonstrated:
Garcia-Carreras et al. 2010

Albedo control on Sahara
Messager et al. 2010
Marshall et al. (GERBILS )
Cuesta et al. ASL 2009

Taylor et al. 2005: AEWs have a significant coupling with soil moisture.
Parker 2008 models dynamics of coupling
Baldi/Dalu 2008

UM at 4km can represent storm initiation. Gravity wave and soil moisture both necessary. Birch et al 2012

Cascade soil moisture stats. (AMMA-2: in progress).

MCS propagates towards soil moisture in COSMO model. Gantner and Kalthoff 2010
Mechanisms of local feedback explained. CRM/LEM shows suppressed precip over forest. Garcia-Carreras et al. 2010, 2011

Hartley project in progress: how is mesoscale rainfall controlled by vegetation?

Bain et al. AEW (2011) involves soil moisture in model.


A solved problem?
Surface state controls the daytime PBL, with convergence and instability on downwind edge of hot surface. This controls 1/8 of storm initiations in the region – a process which GCMS represent wrongly, although explicit-convection models capture it. At the same time, rainfall can be suppressed over cooler adjacent areas. Inversely, organised convection tends to propagate over available moisture, and rains more on wet surfaces. Synoptic AEWs have a soil moisture signal with evidence of feedback.

AMMA-UK land-atmosphere interaction studies 2005-2012.
(Slide courtesy Doug Parker)
Example emerging finding from aircraft survey

FLIGHT CASE STUDY:
COMPARING N/S FLIGHTS TO STUDY ONSET EVOLUTION OF 2016
Considerable advance of monsoon rains between 13 & 28 June, later than normal

Above: accumulated rainfall between 1 June 2016 and 13 or 28 June; normal position by these dates also shown

Left: Change in volumetric soil moisture between 13 & 28 June [%], 3-day average in each case

Courtesy Chris Taylor, AMSR2 satellite

SM courtesy: Chris Taylor
Comparison of flight & reanalysis atmospheric thermodynamics

- Good agreement between ERA-Interim and flight quantities
- Clear disappearance of dry-air intrusion at mid-levels by 28 June

ERA-Interim equivalent potential temperature ($\theta_e$, shaded) and from flights b958 & b967 (circles)

Courtesy: Bryn New
Atmospheric profiles on 13 & 28 June

- Clear gradient between deep, moist layer extending from the surface in the south to warmer but dryer column in the north.

As we shall see, by 28 June the northward advance of the monsoon moistens the column through considerable depth, extending further northward.
MODELLING CASE STUDIES IN INCOMPASS
Next steps: case studies with nested high-resolution modelling

- Nested region set-up
  - Resolution: 4.4km (convection permitting)
  - Development of new land ancillaries
  - Daily updating from OSTIA SST

- Driving global model set up:
  - Resolution: N768 (~17km)
  - Frequency: Daily at 00Z

Much of the following work will involve comparison of Met Office model (MetUM) experiments at variety of resolutions with observational data:

- “Standard” resolution of 4.4km
- Tests on further limited domain O(100m)
Forecast comparison for informing flights

- Met Office global operational model
  (~17km resolution)

- Regional model
  (~4 km resolution)

Operated a dedicated 4.4km LAM forecast for the field campaign period in addition to UK Met Office standard global operational model (N768; ~17km)

Both forecasts for 27 June 1030LT