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

AG Turner, GS Bhat and many others

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part of the NERC/MoES Monsoons Programme 2015-2018

MoES/NERC Monsoons Programme

- 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

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INCOMPASS scientific interest

- 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…)

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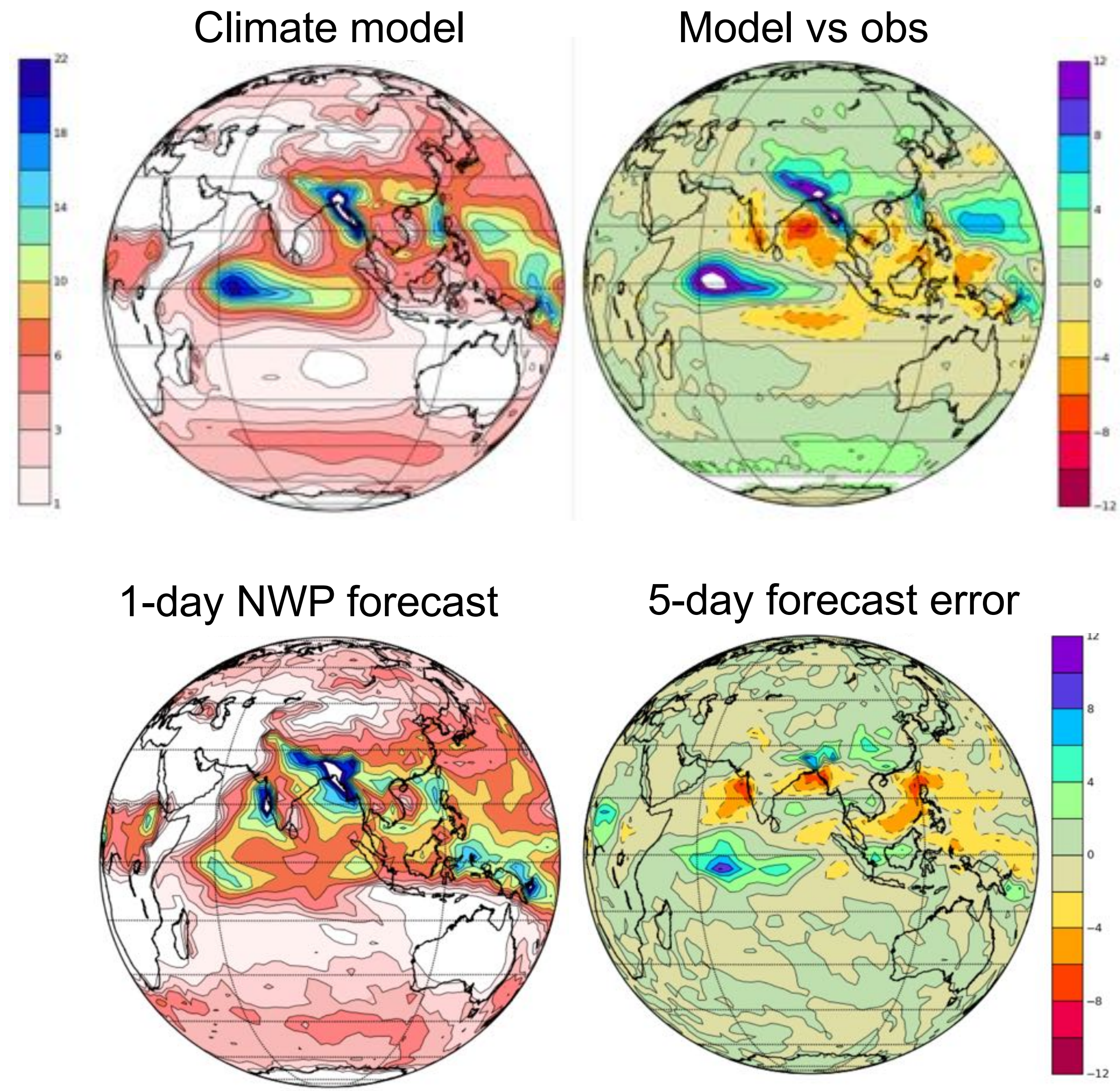
Met Office Hadley Centre

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

- 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



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GEWEX Open Science Conference, 7 May 2018

THE CONSORTIUM

INCOMPASS partner institutes

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

UNIVERSITY OF LEEDS

India Meteorological Department

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Indian Institute of Technology Kanpur

Met Office

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NCMRWF

CSIR- National Aerospace Laboratories
Aerospace Technologies for Today and Tomorrow
ISO 9001:2008 Certified

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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 Recchia, Luis Garcia-Carreras…
- CEH: Chris Taylor, Jon Evans, Danijel Belusic, Ross Morrison +…

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THE ATMOSPHERIC RESEARCH AIRCRAFT & FLIGHT STRATEGY

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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

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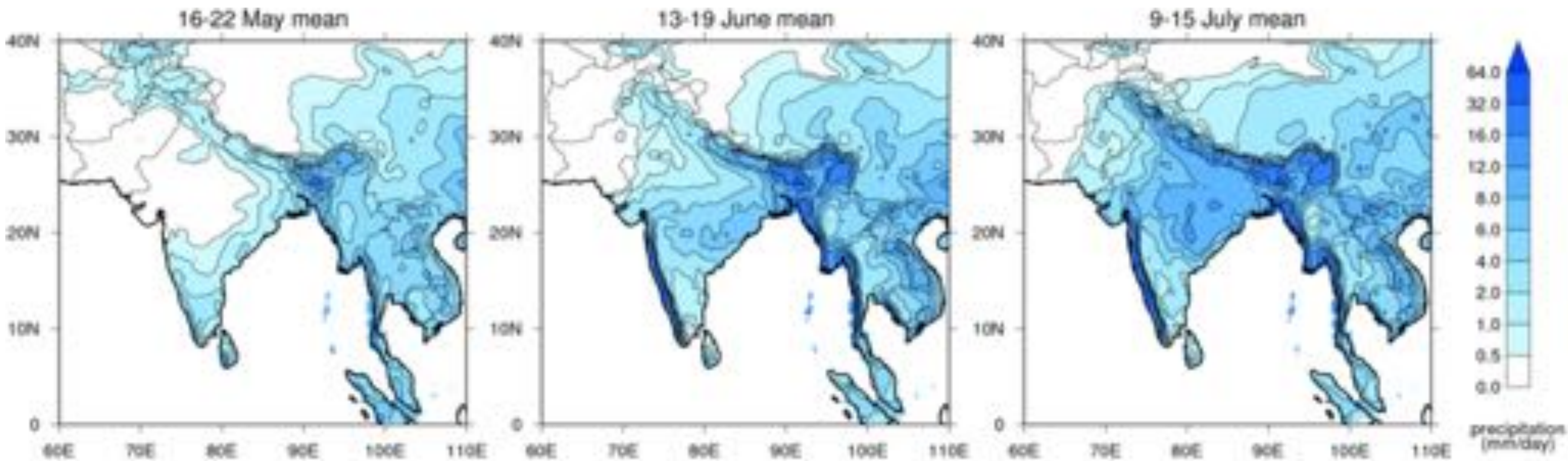
part of the NERC/MoES Monsoons Programme 2015-2018



Based on APHRODITE data 1951-2007

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

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Distribution of 22 flights performed June/July 2016; 2 airport bases

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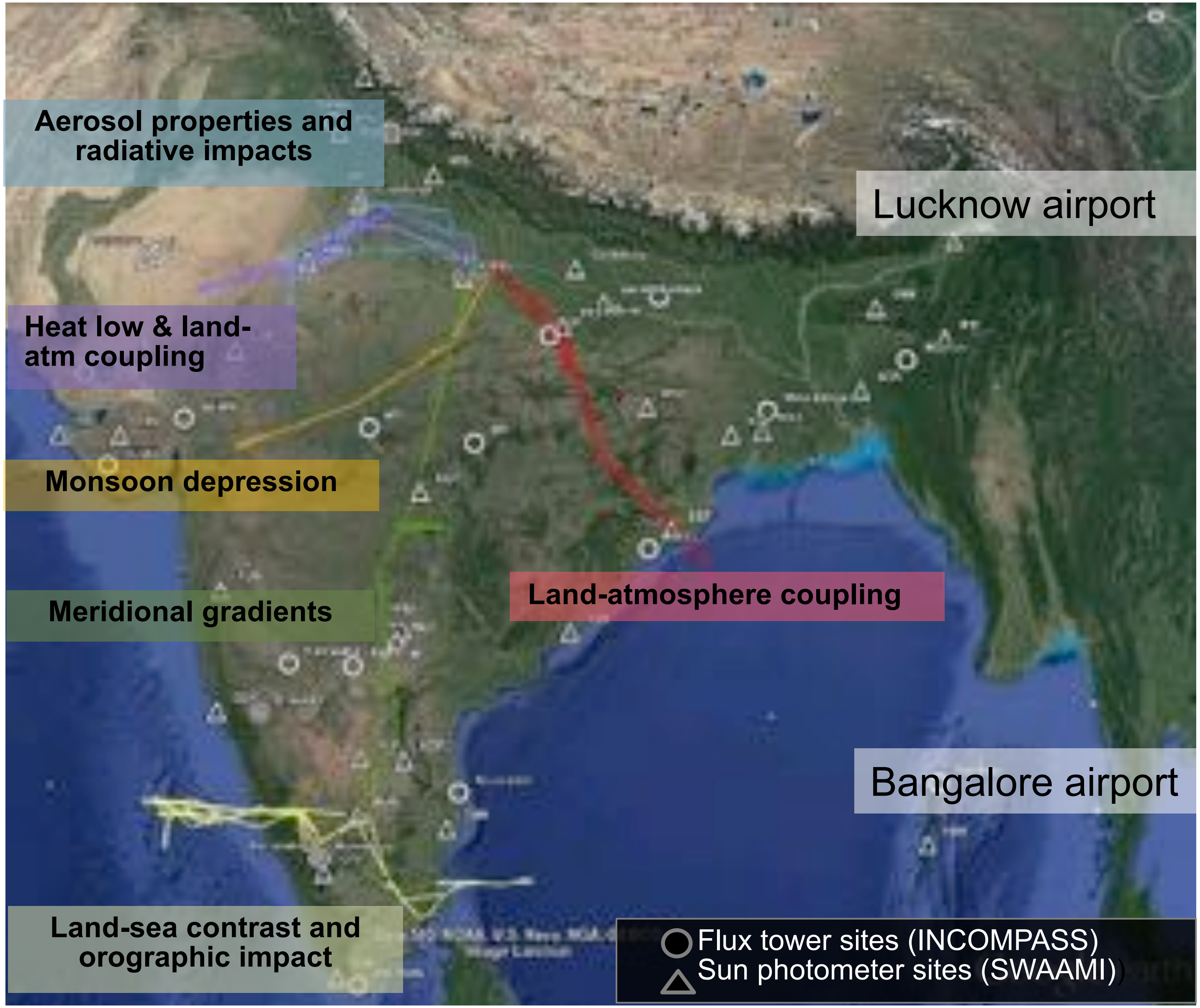

Pre-planned and responsive flights

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)

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Image courtesy Gill Martin/Justin Langridge, Met Office

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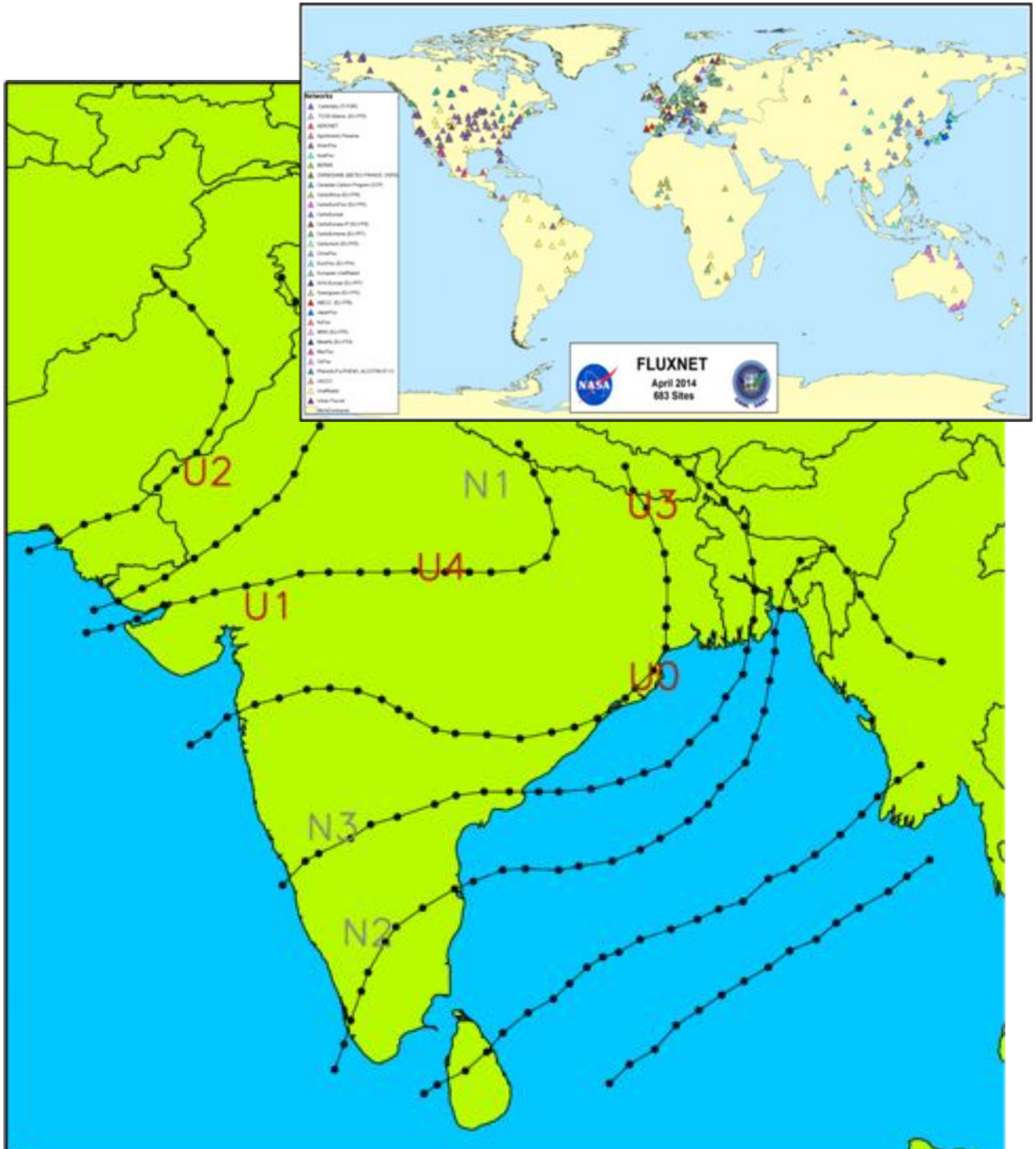
GROUND COMPONENTS OF THE FIELD CAMPAIGN

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)

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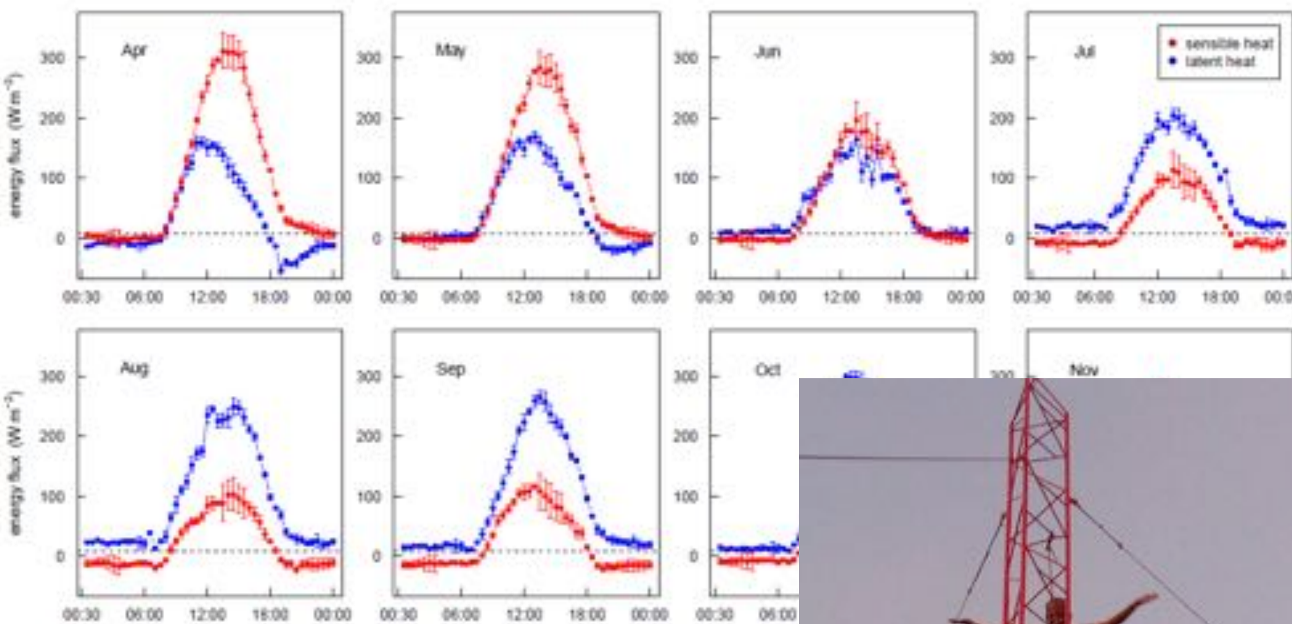
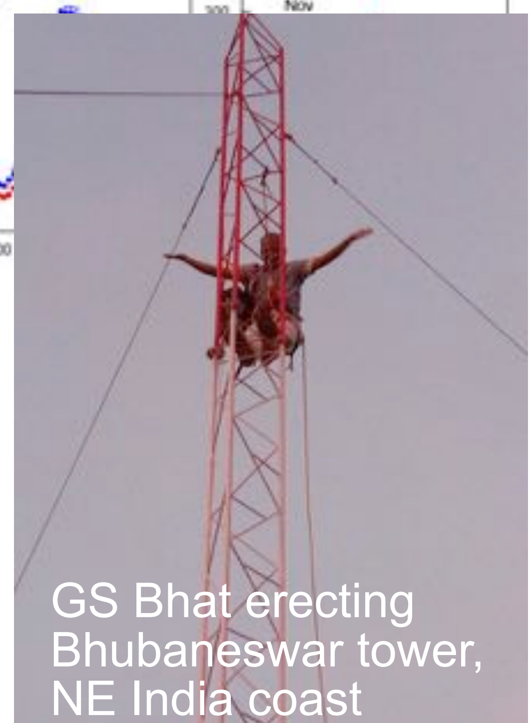
Example flux measurements

Partitioning between SH and LH fluxes at **Dharwad** through 2016 (Courtesy: Ross Morrison, CEH)

Measurements to continue for many years to come





IIT-Kanpur supersite (~85km to Lucknow)

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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

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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

INCOMPASS project
part of the NERC/MoES Monsoons Programme 2015-2018

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

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In-situ aircraft data from low-level transect

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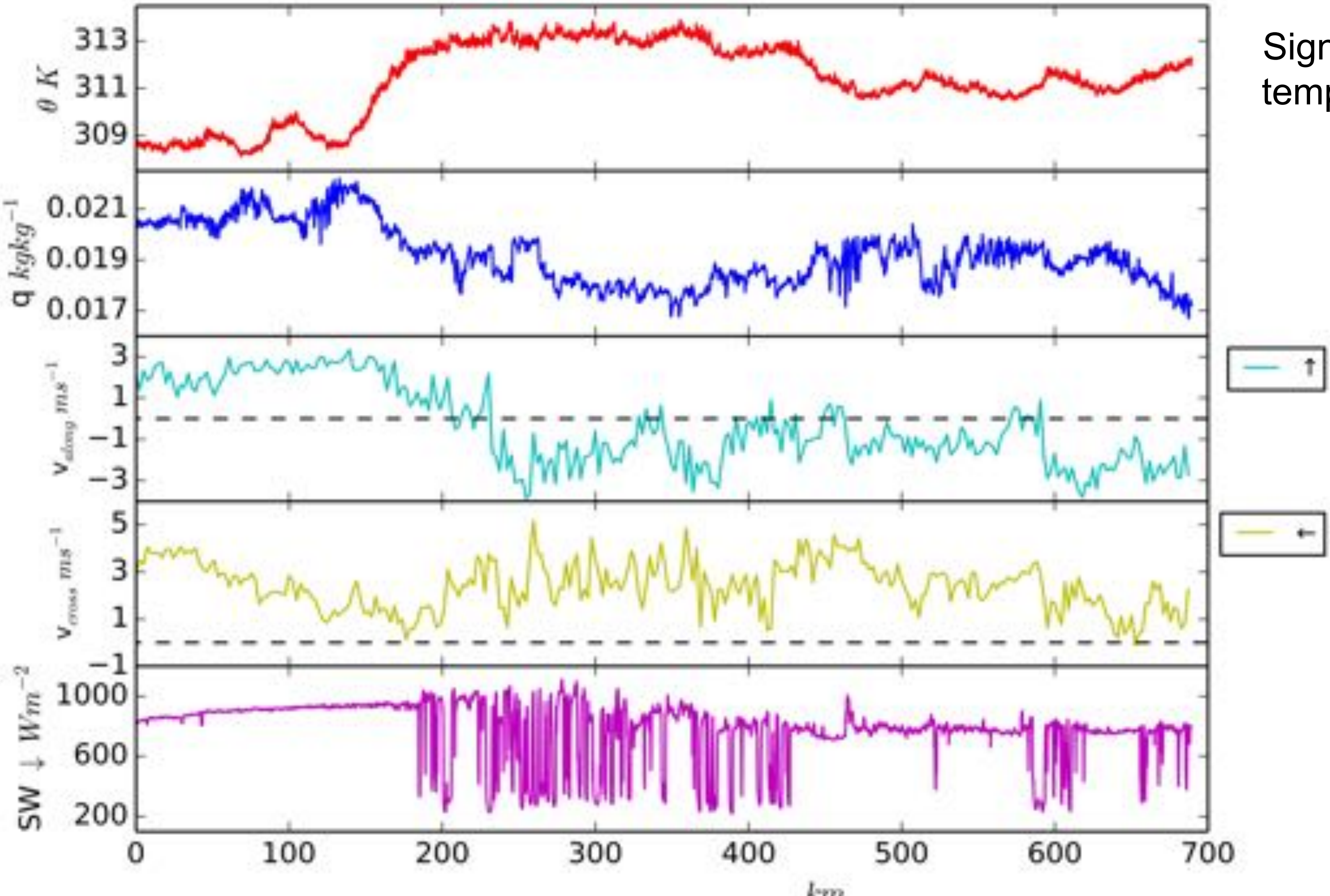

Distance along low-level track →

Significant horizontal temperature gradient $\Delta T_{max} \approx 5°C$

Strong variations in along- and cross-track winds

Courtesy: Emma Barton/Chris Taylor CEH

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Potential temperature & wind at flight level

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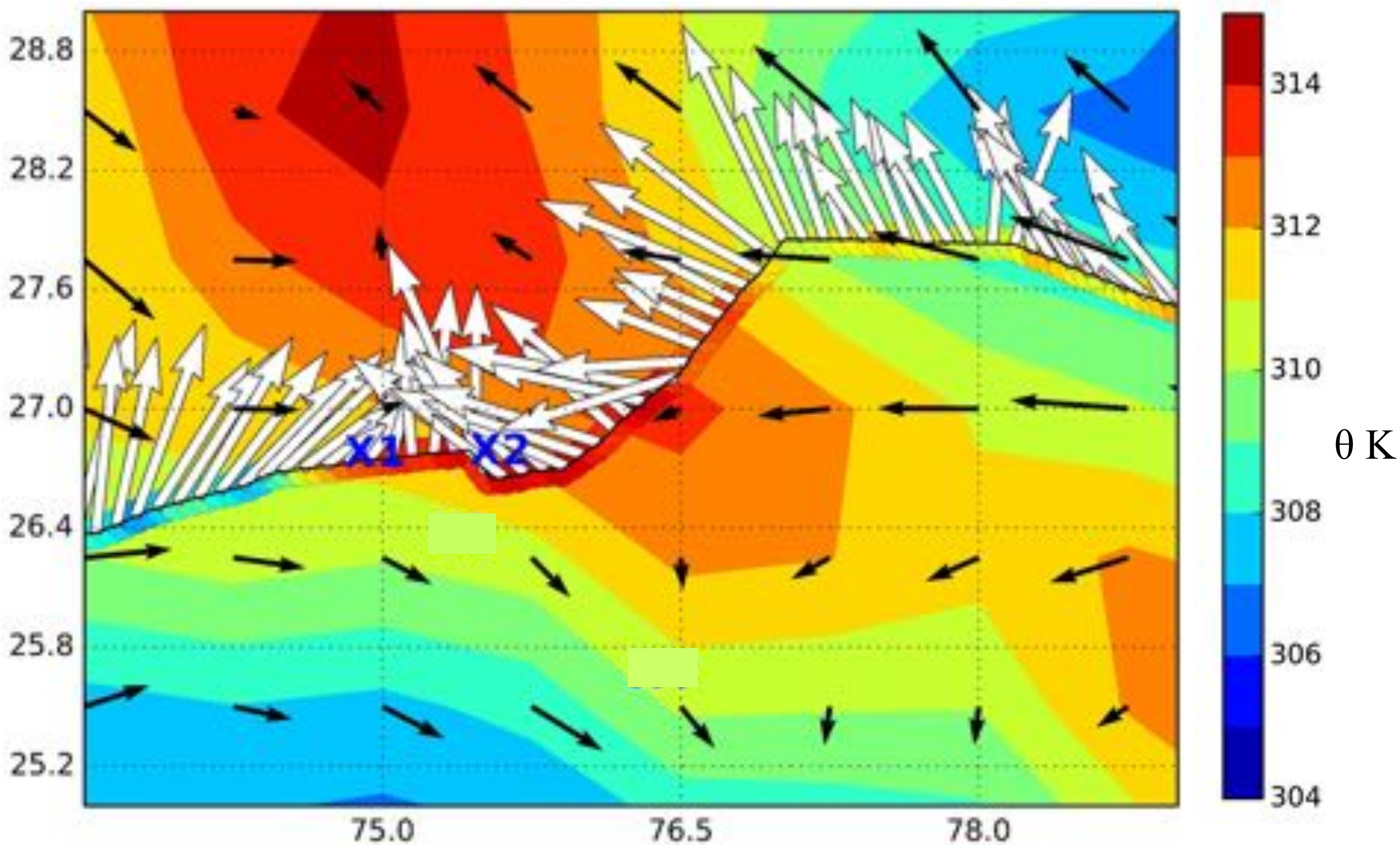
Large-domain comparison with ERA-Interim



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

Courtesy: Emma Barton/Chris Taylor CEH

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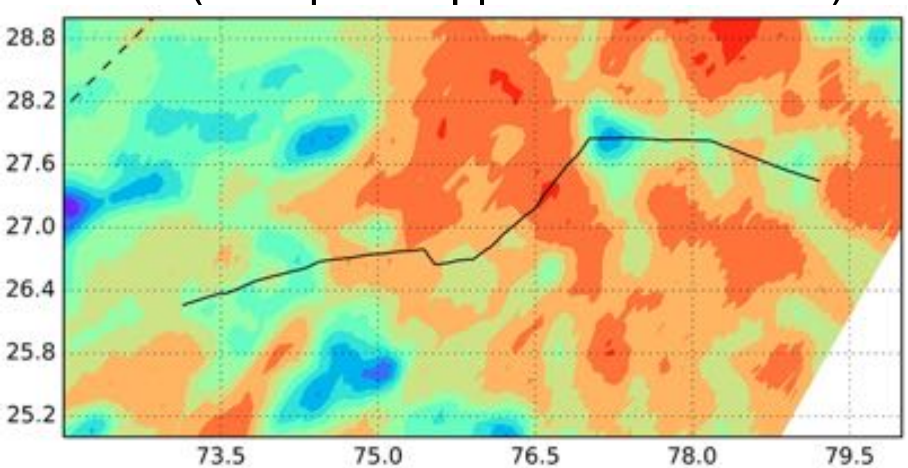
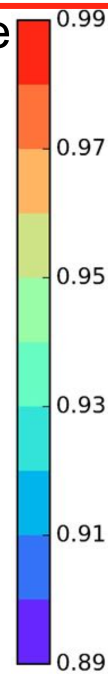
Satellite-derived soil moisture (proxy)

Polarization ratio derived from
GPM 10.7 GHz brightness temperature
(Overpass approx. 03:20 UTC)

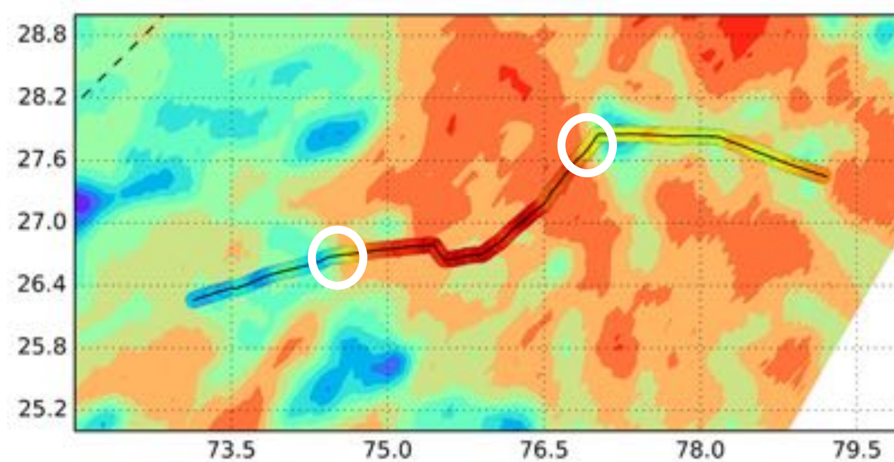


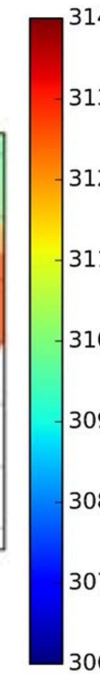
drier soils



wetter soils

…with potential temperature (K)
along flight track





"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

Courtesy: Emma Barton/Chris Taylor CEH

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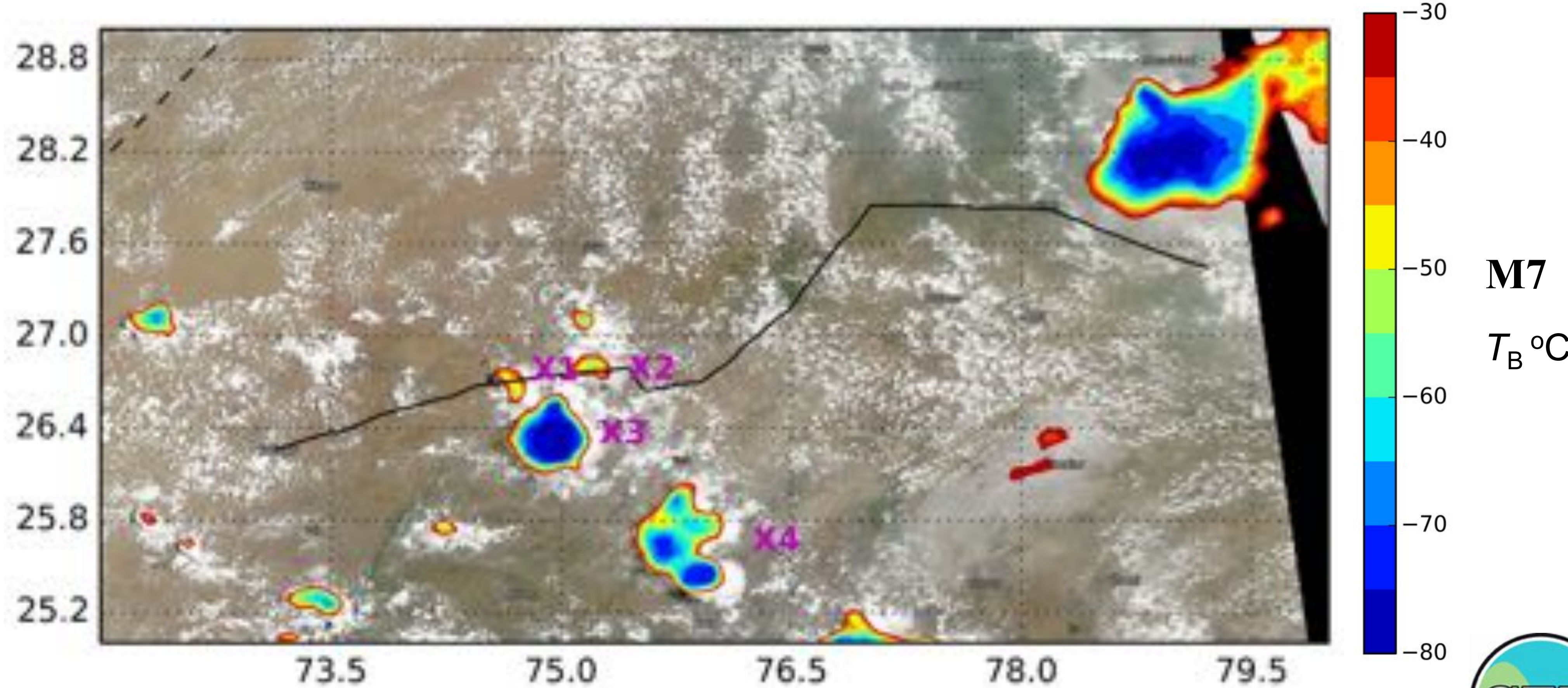
Development of post-flight clouds (afternoon)



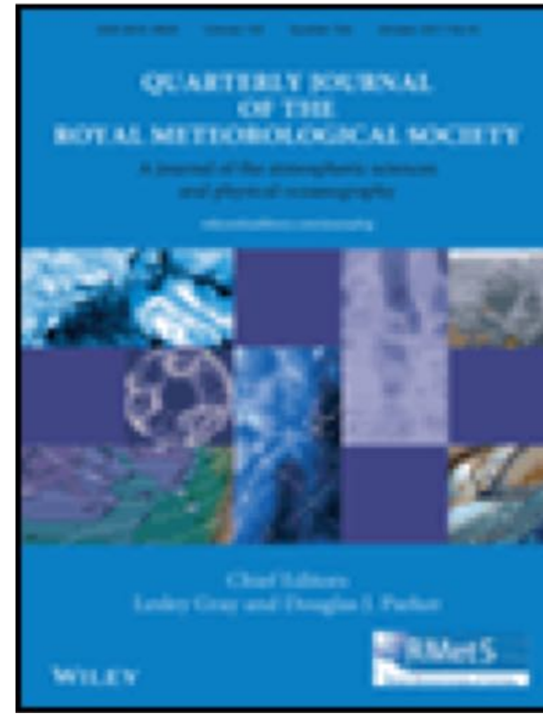
X# = initiation of deep convention (when cloud top brightness temperature drops below -30°C)

Courtesy: Emma Barton/Chris Taylor CEH

Summary

- 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

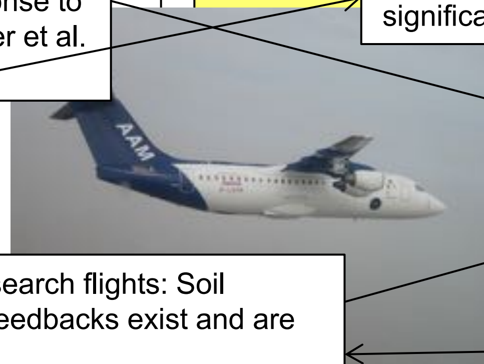
Observations - > -> - > -> - > -> - > -> - > -> - > -> - > -> - > -> Models

Earlier work	AMMA field studies	Remote sensing	Theory and process studies	CRM:	LAM:	GCM

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

JET2000:
Taylor et al. 2003: thermodynamic feedback, and evidence of rainfall response.
Parker et al. 2005a/b, some evidence of dynamic response.

Surface data used to explain PBL response to rain: Kohler et al. 2010



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
Marsham et al. (GERBILS)
Cuesta et al. ASL 2009

Soil moisture triggers storms (1/8).
Taylor et al. Nature Geo., 2011

Taylor et al. 2005: AEWs have a significant coupling with soil moisture.

Parker 2008 models dynamics of coupling

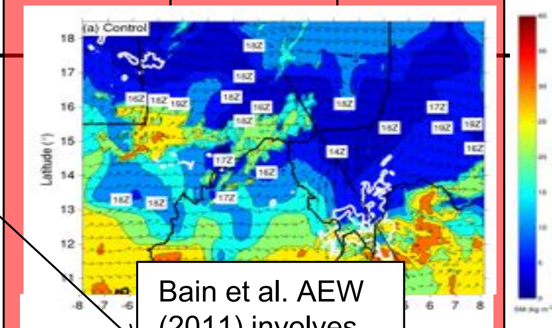
Baldi/Dalu 2008

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

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?



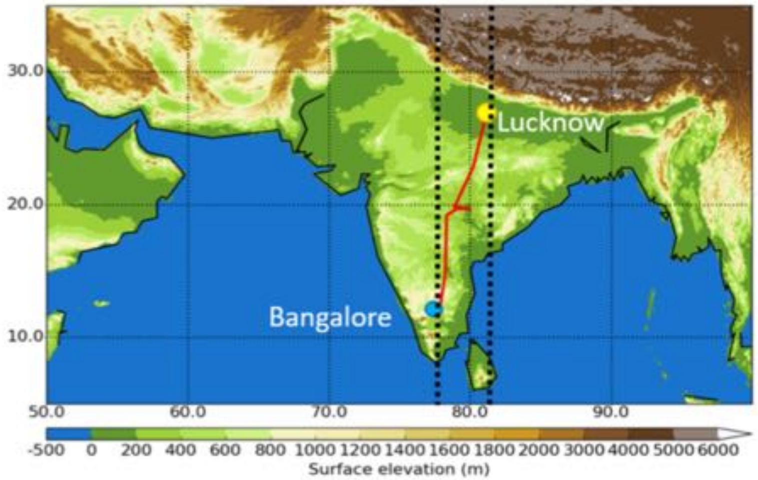
Bain et al. AEW (2011) involves soil moisture in model.

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

Taylor et al. Nature 2012: GCMs have wrong sign of feedback on afternoon rainfall.

AMMA-UK land-atmosphere interaction studies 2005-2012. (Slide courtesy Doug Parker)

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



Example emerging finding from aircraft survey

FLIGHT CASE STUDY: COMPARING N/S FLIGHTS TO STUDY ONSET EVOLUTION OF 2016

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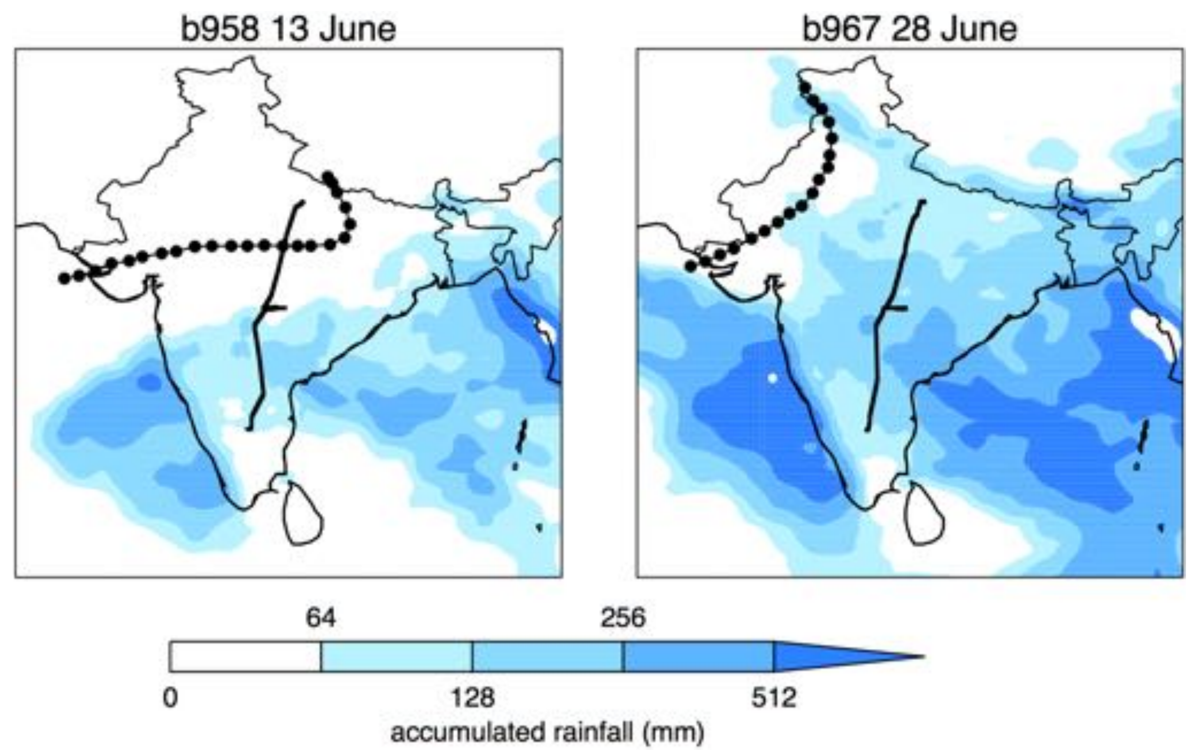
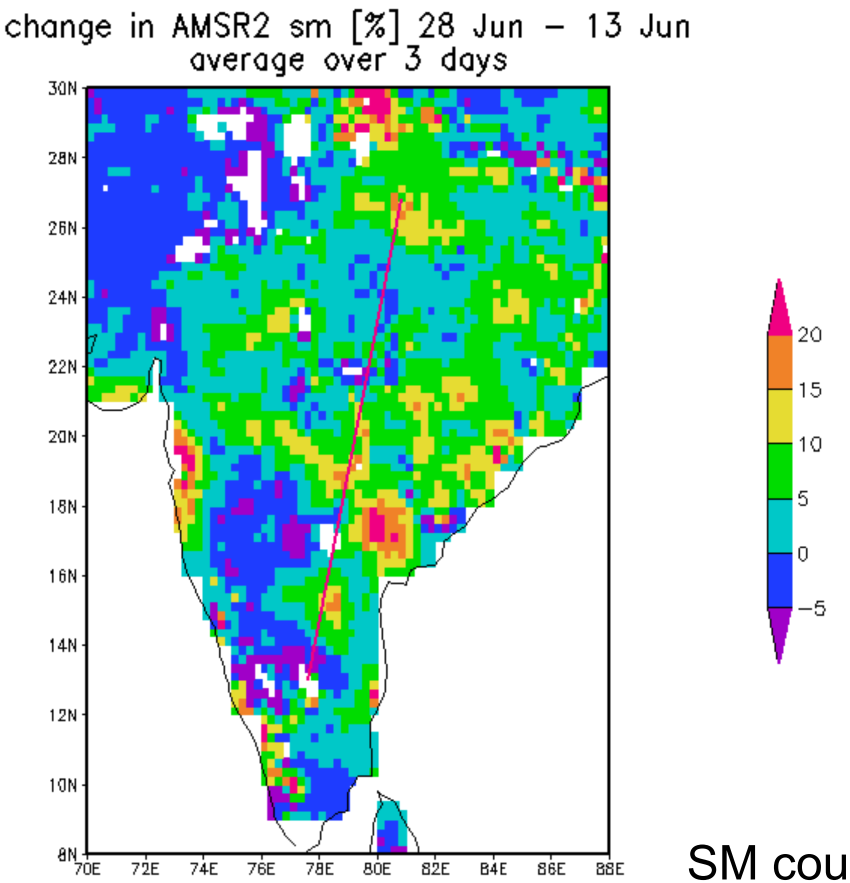
Monsoon advance between the transit flights: compare 13 & 28 June

- 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

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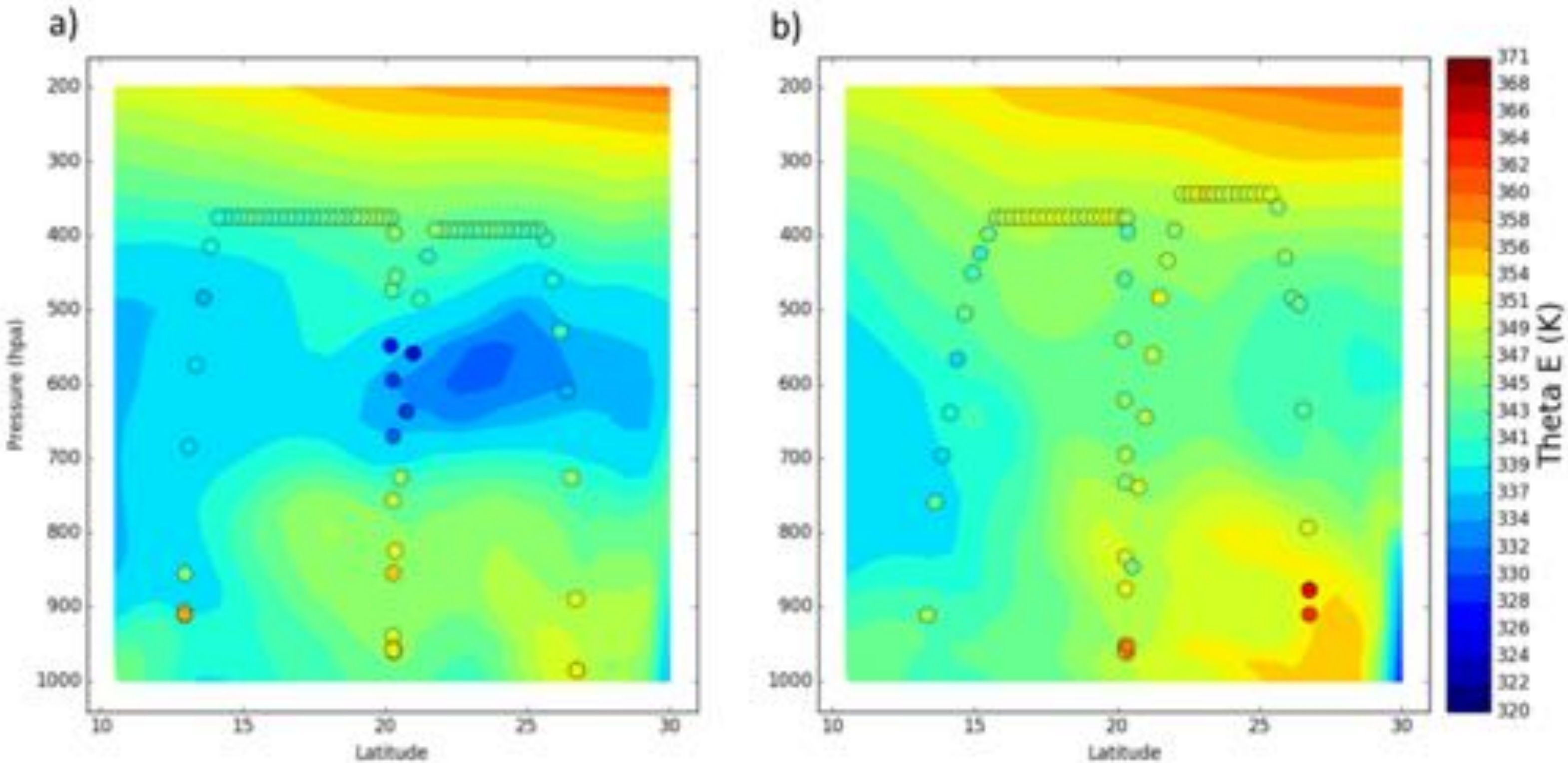
Comparison of flight & reanalysis atmospheric thermodynamics



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

Courtesy: Bryn New

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

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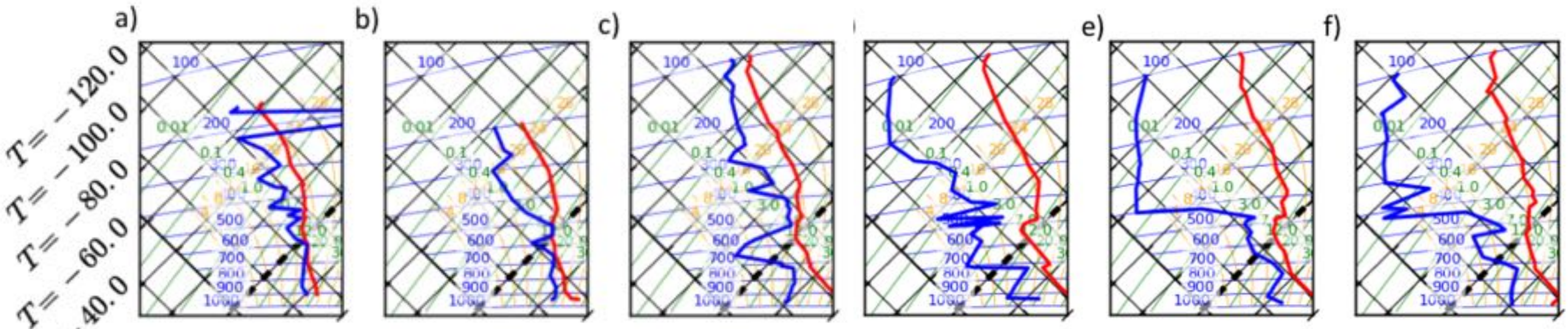
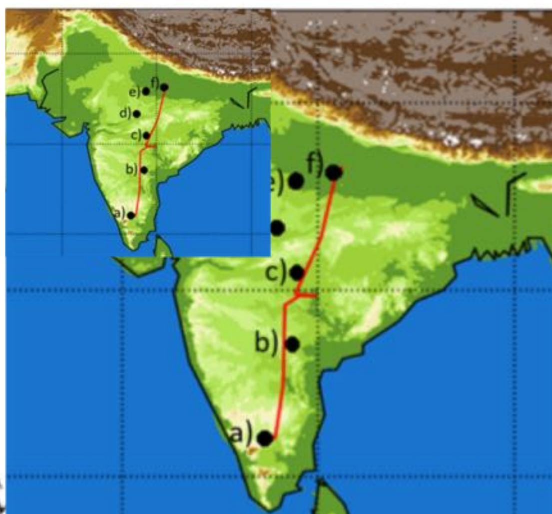
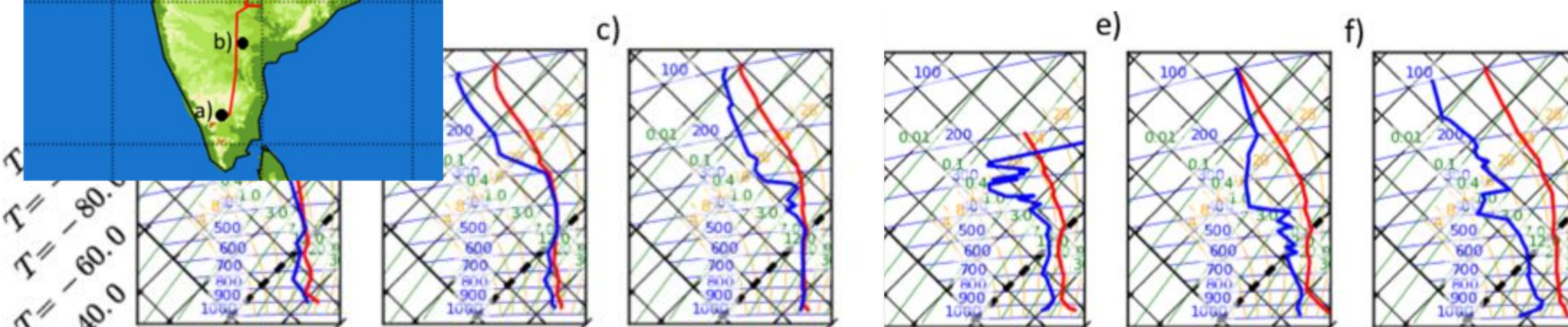
Atmospheric profiles on 13 & 28 June



SOUTH → NORTH



- Clear gradient between deep, moist layer extending from the surface in the south to



considerable
northward

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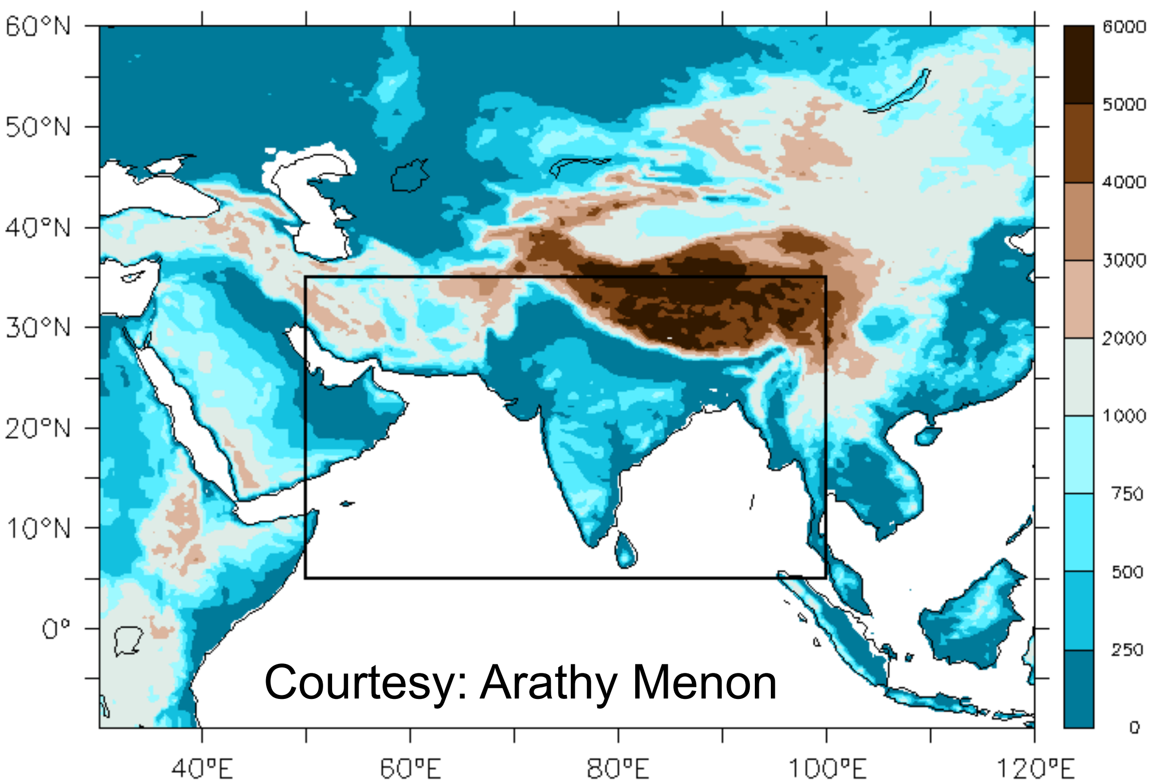
MODELLING CASE STUDIES IN INCOMPASS

Next steps: case studies with nested high-resolution modelling

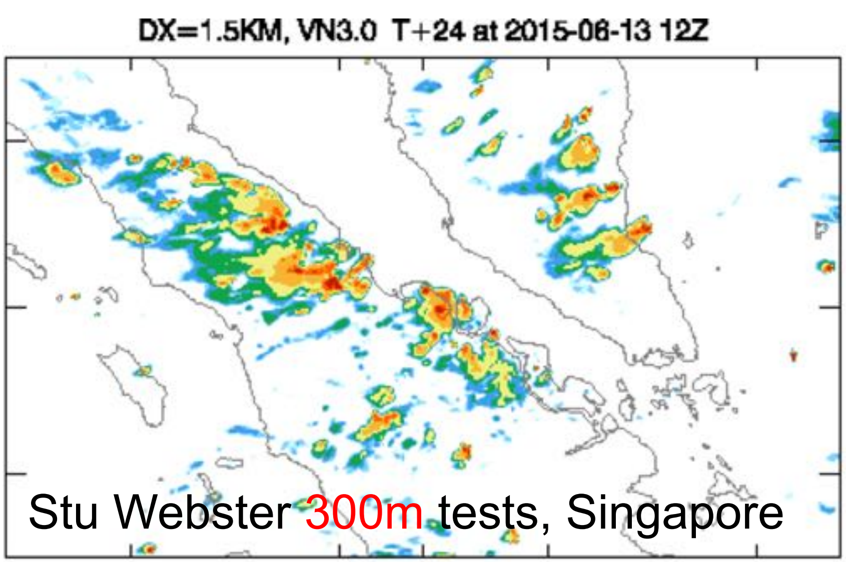


Nested region set-up
- Resolution: 4.4km (convection permitting)
- Development of new land ancillaries
- Daily updating from OSTIA SST

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

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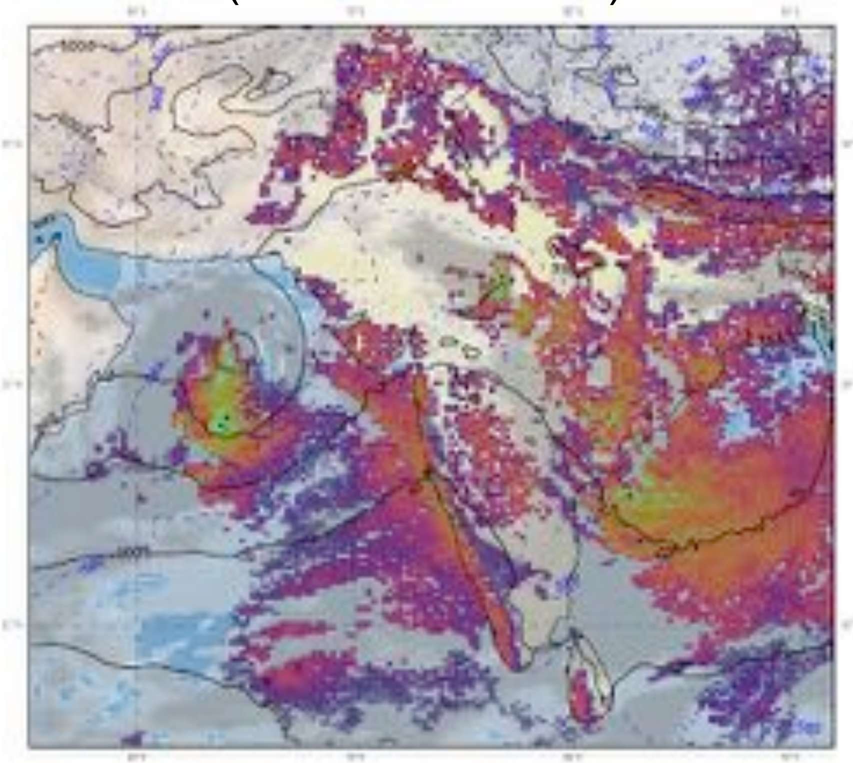
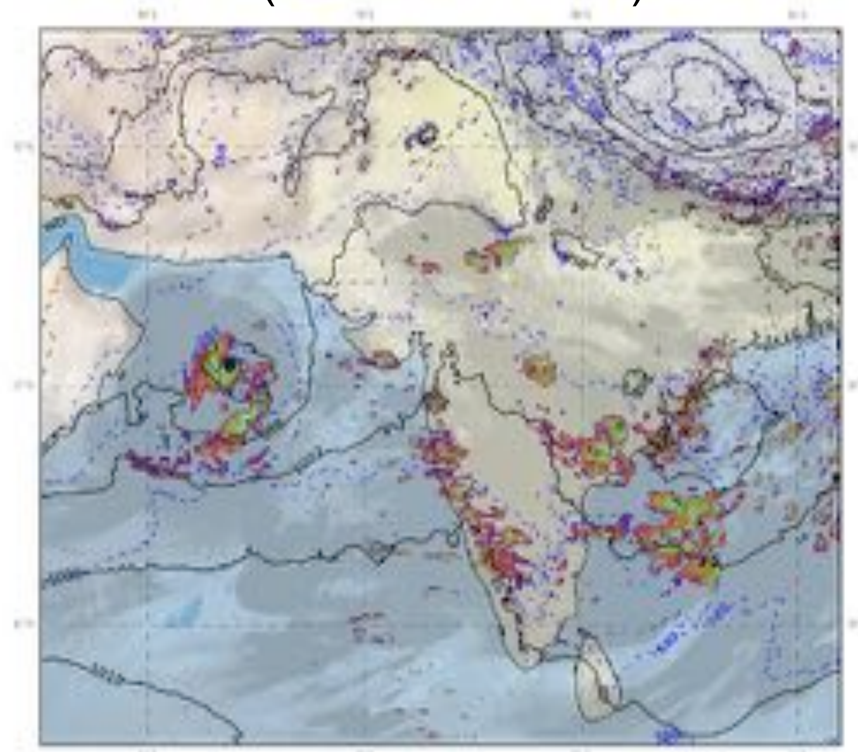
Met Office global operational model
(~17km resolution)



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

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