Atmospheric Science Conference
2-3 July 2019, Birmingham

RMetS
Royal Meteorological Society

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

AG Turner, GS Bhat and many others

INCOMPASS project

part of the NERC/MoES Monsoons Programme 2015–2018

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Ministry of Earth Sciences
Government of India

NERC SCIENCE OF THE ENVIRONMENT

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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 tests at ~300m

Ultimate, long-term goal:

- To improve skill of monsoon rainfall prediction

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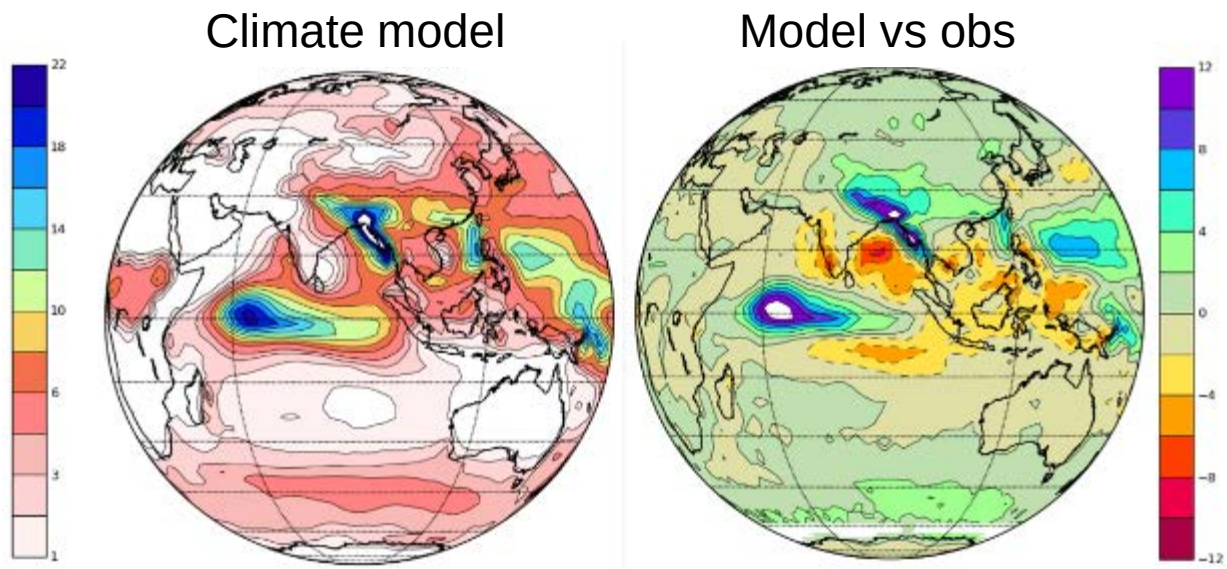
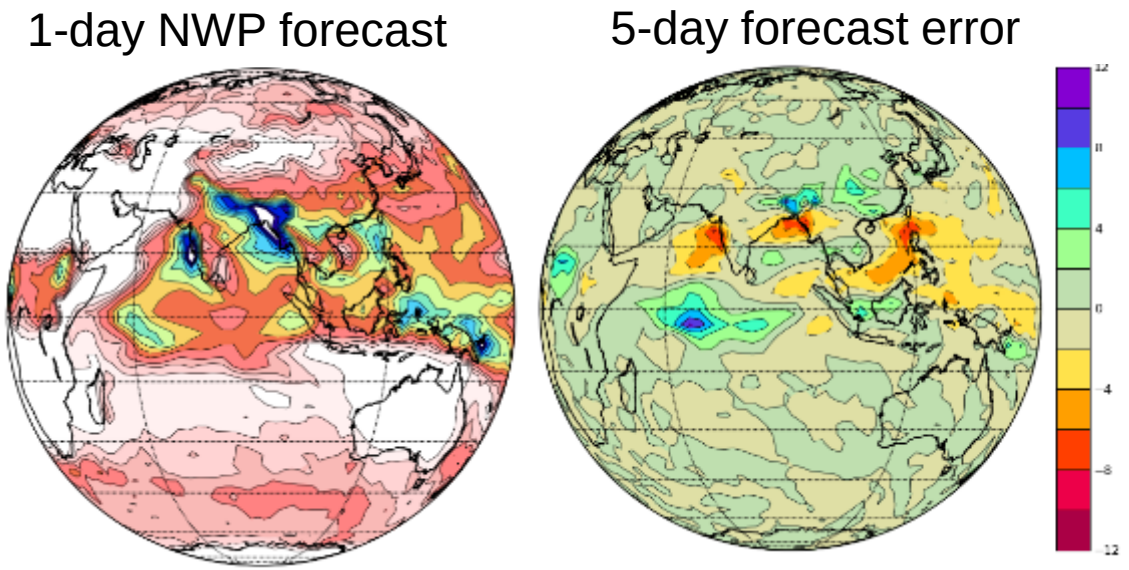
Bias development in the MetUM (or many others…)

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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THE CONSORTIUM

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INCOMPASS partner institutes

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

UNIVERSITY OF LEEDS

University of Reading

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

Met Office

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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)

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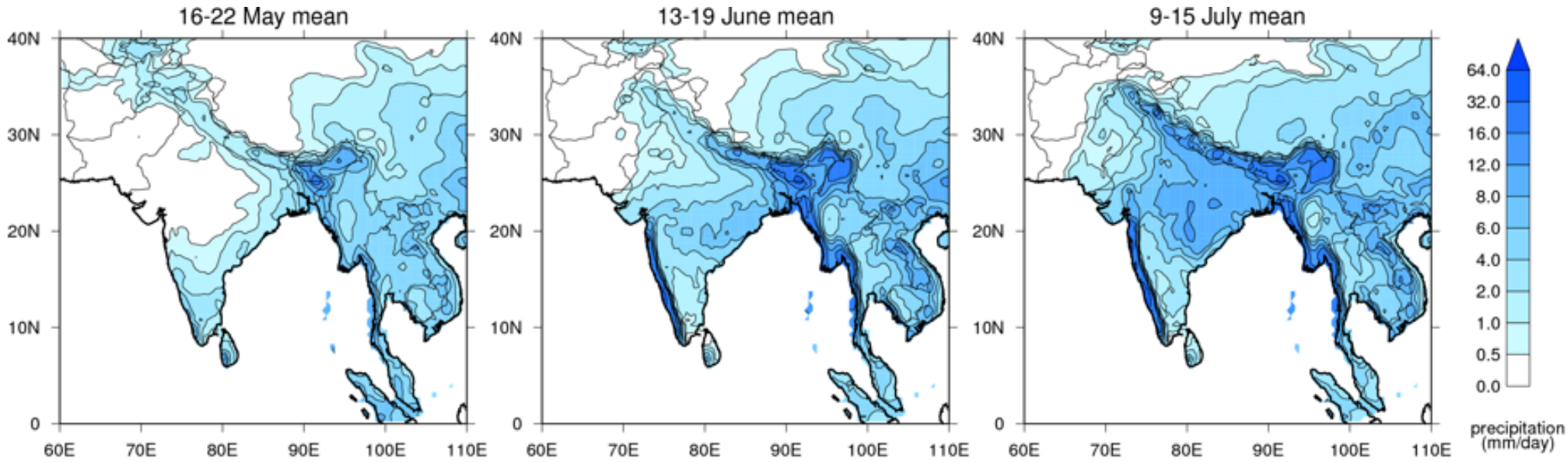
Overall INCOMPASS flight strategy



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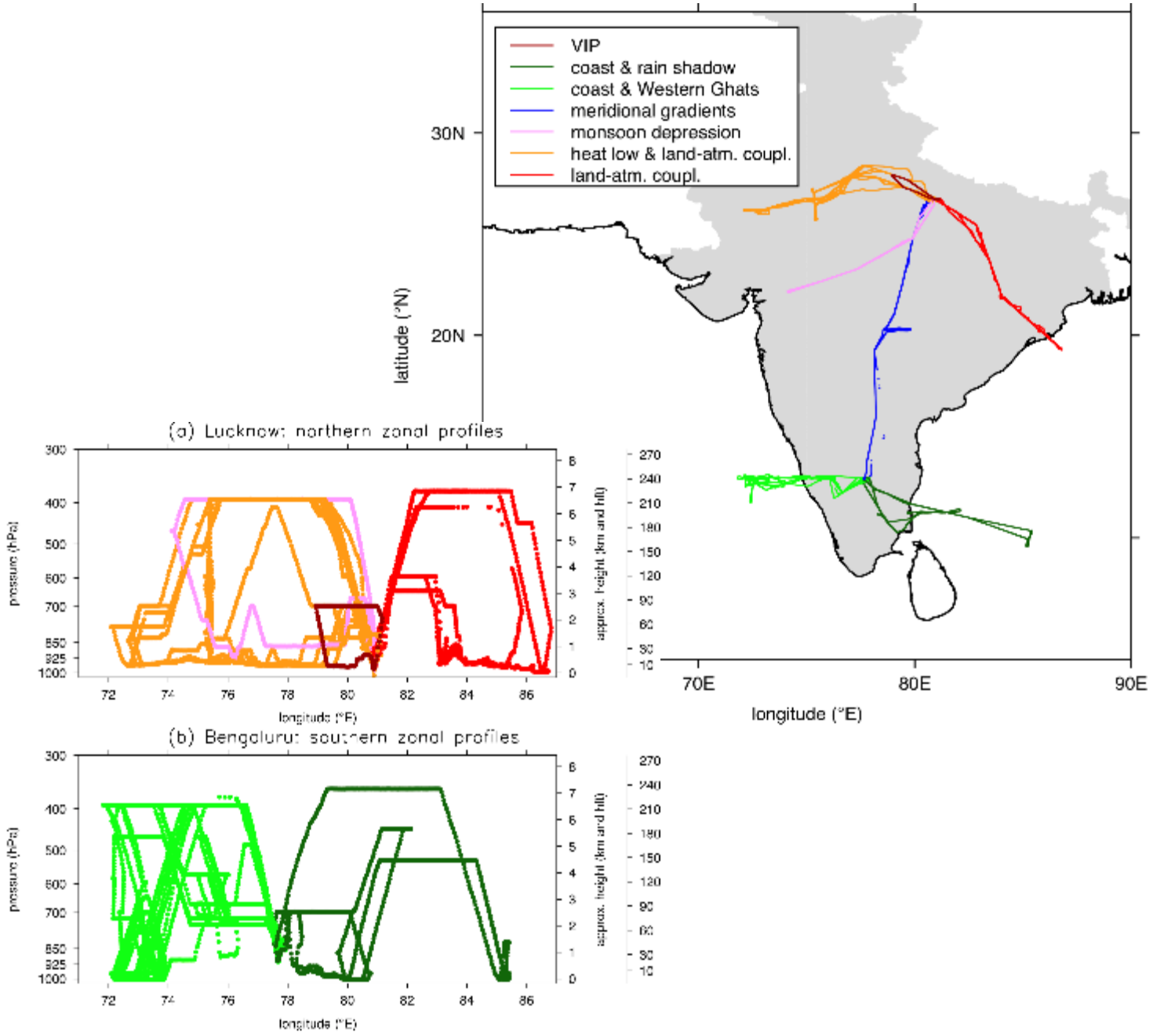
Distribution of 22 flights performed June/July 2016; 2 airport bases



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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GROUND COMPONENTS OF THE FIELD CAMPAIGN

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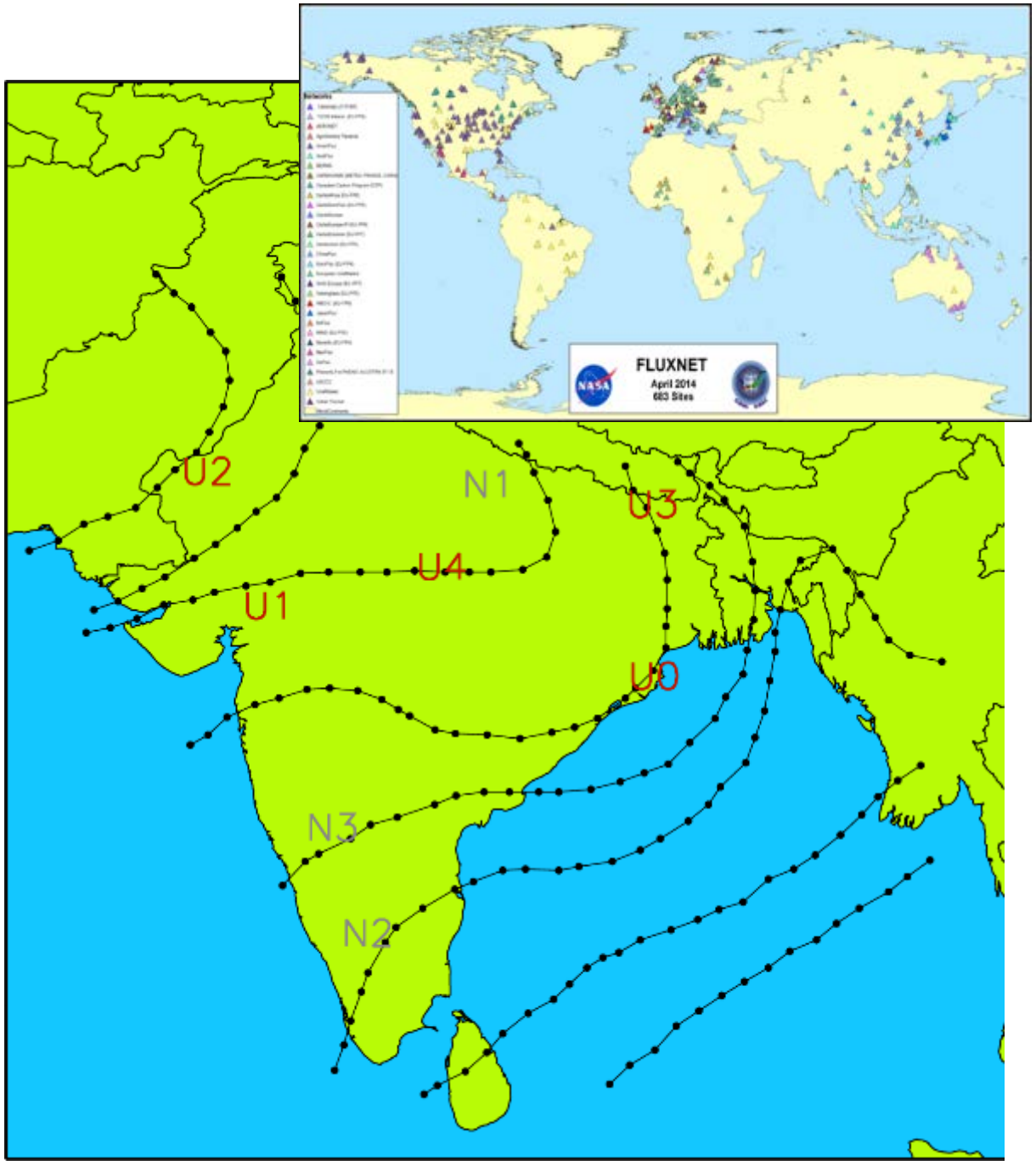
Flux towers



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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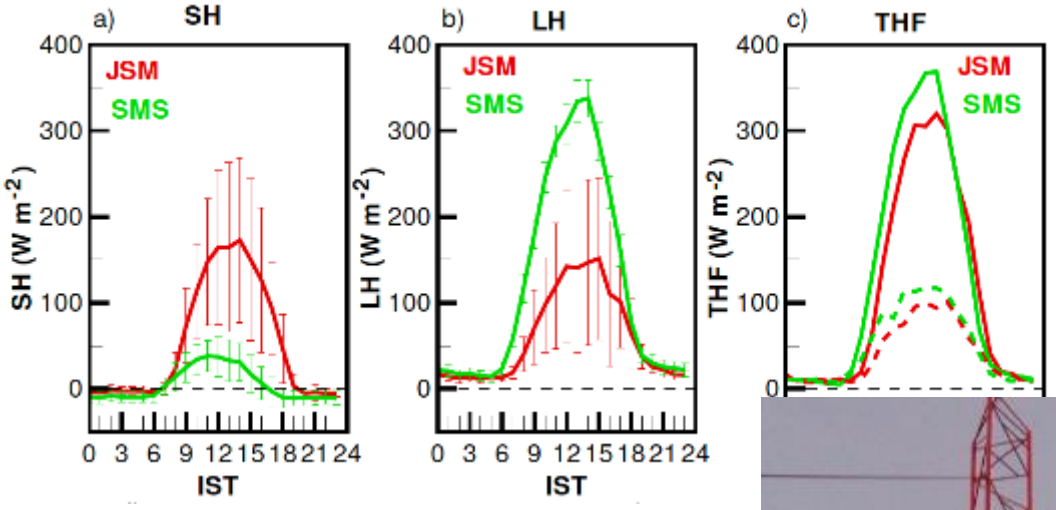
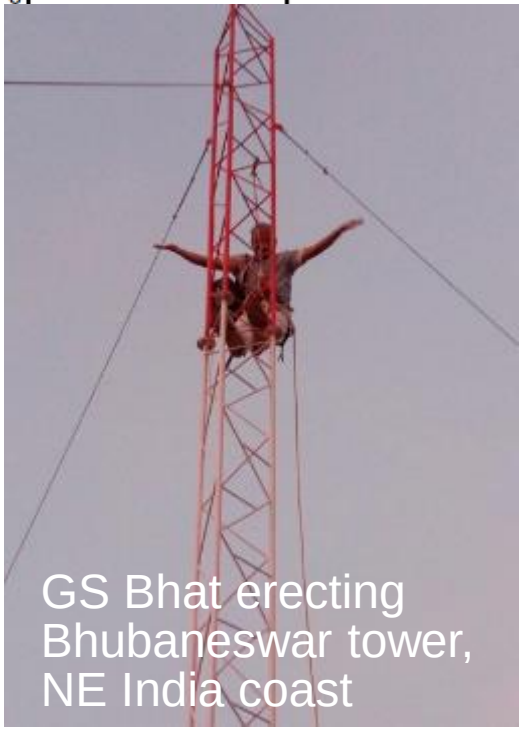
Example flux measurements

Partitioning between SH and LH fluxes at **Samastipur** and **Jaiselmer** through August 2016 (Courtesy: GS Bhat, IISc)



Measurements to continue for many years to come


GS Bhat erecting Bhubaneswar tower, NE India coast


Kanpur site


Dharwad site


Berambadi site

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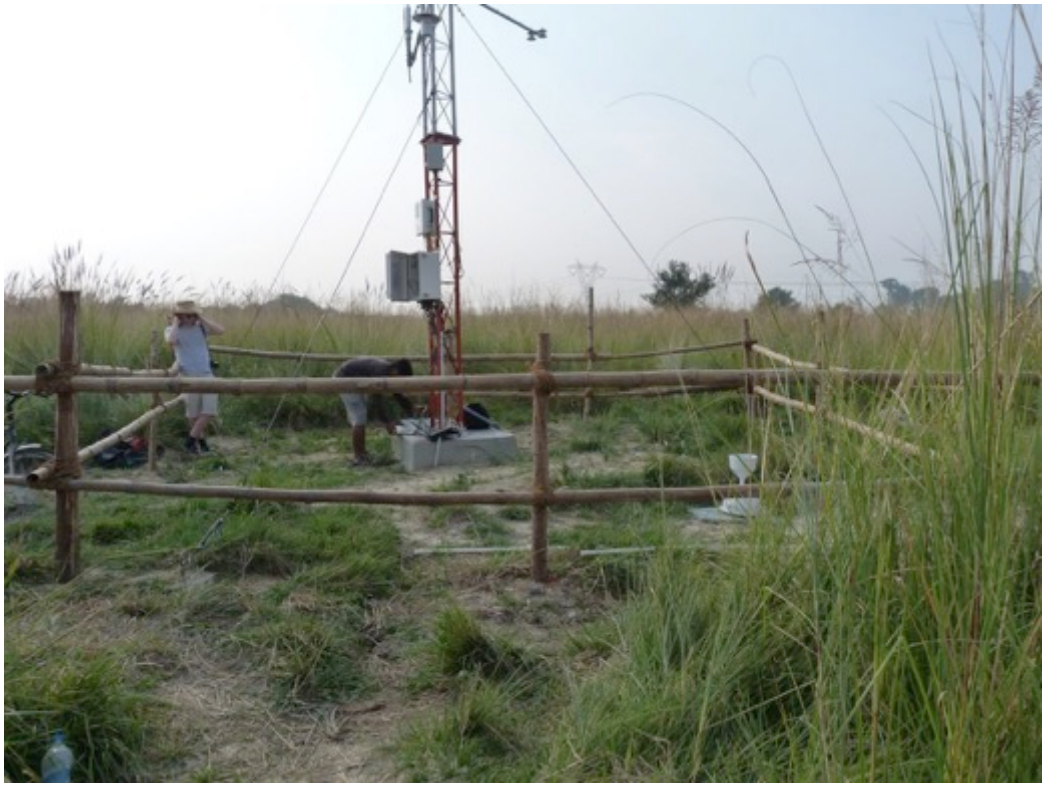
IIT-Kanpur supersite (~85km to Lucknow)



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

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Example emerging finding from aircraft survey

FLIGHT CASE STUDY:
SOIL MOISTURE & STORM INITIATION

Emma Barton *et al.* (*QJRMS*, published online)

INCOMPASS project
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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

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CEH

Courtesy: Emma Barton/Chris Taylor CEH

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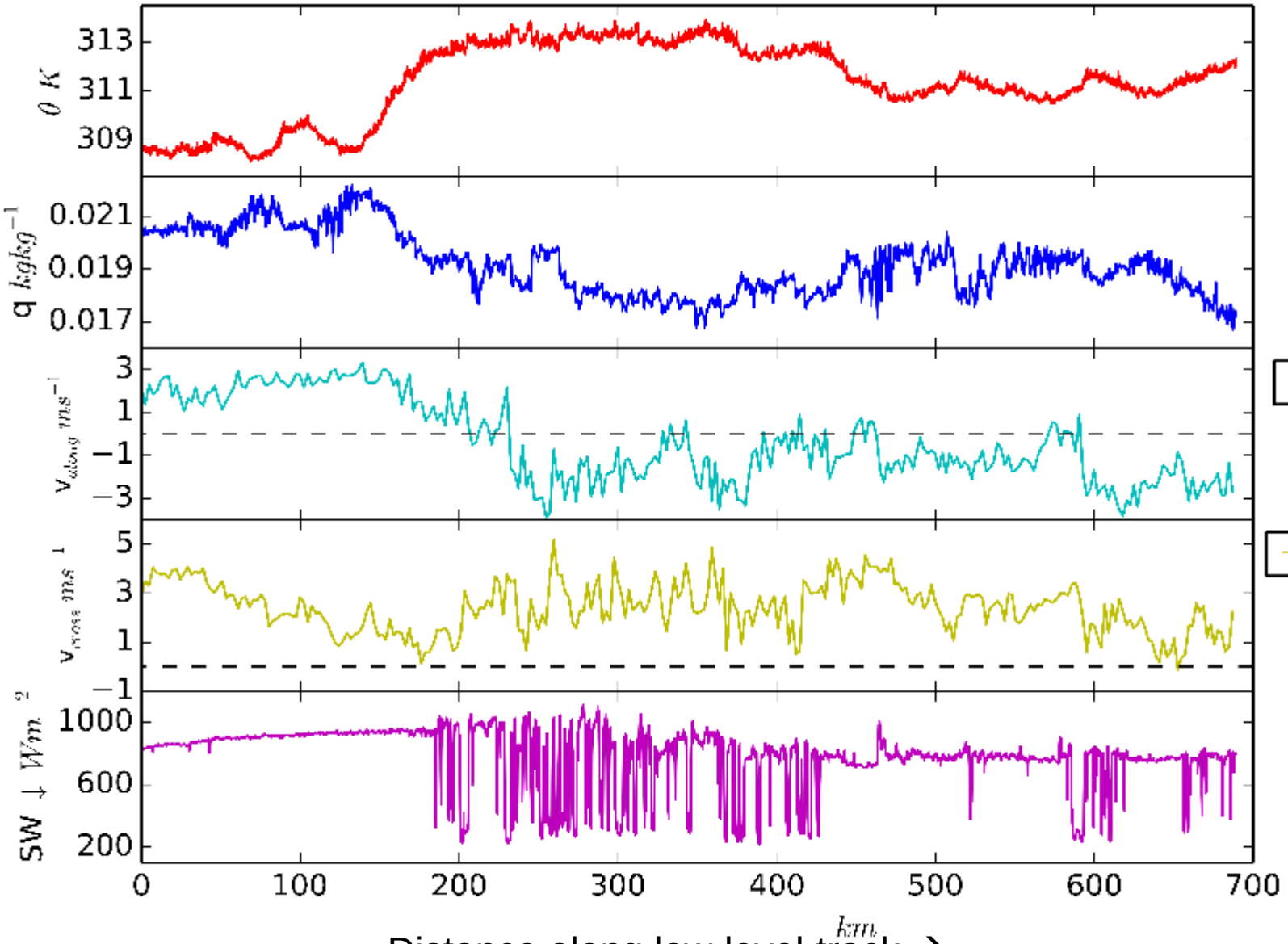
In-situ aircraft data from low-level transect



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

Strong variations in along- and cross-track winds

Distance along low-level track →

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Courtesy: Emma Barton/Chris Taylor CEH

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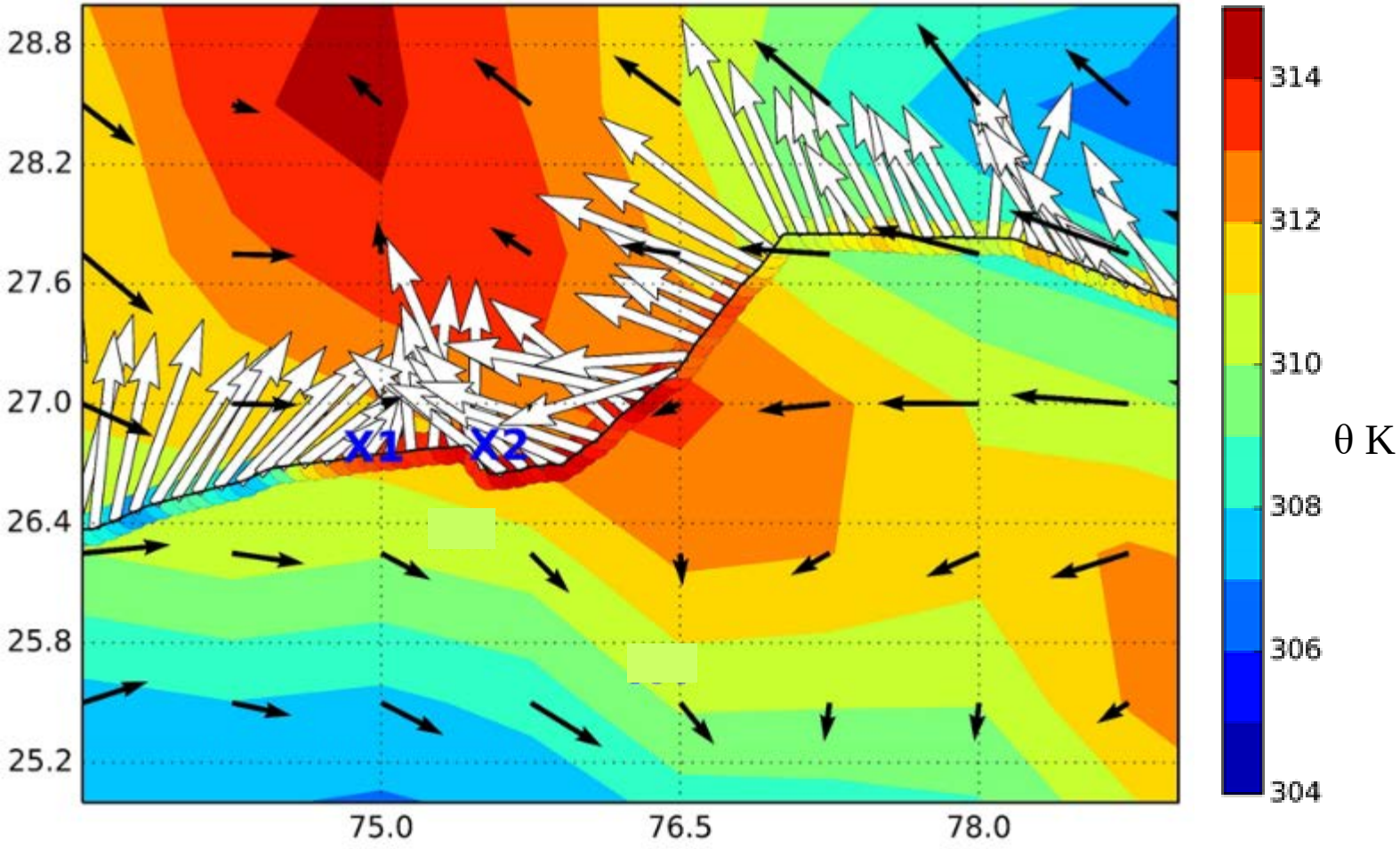
Potential temperature & wind at flight level

Large-domain comparison with ERA-Interim



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

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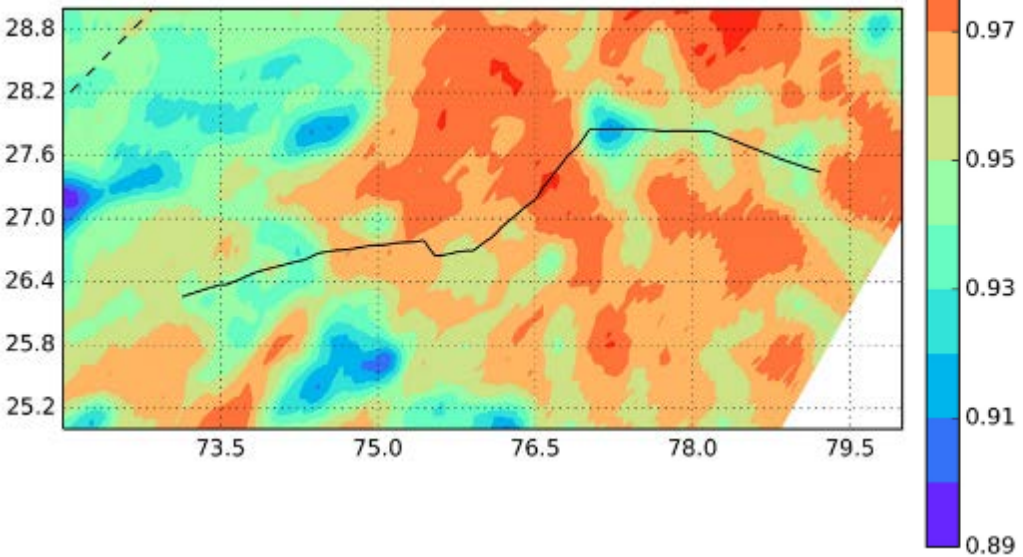
Satellite-derived soil moisture (proxy)

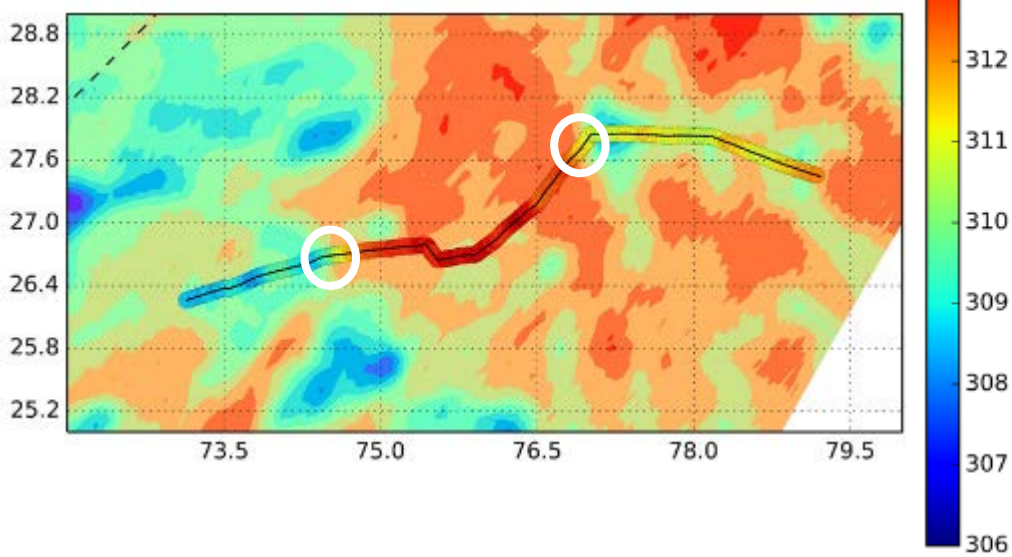
Polarization ratio derived from GPM 10.7 GHz brightness temperature (Overpass approx. 03:20 UTC)

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

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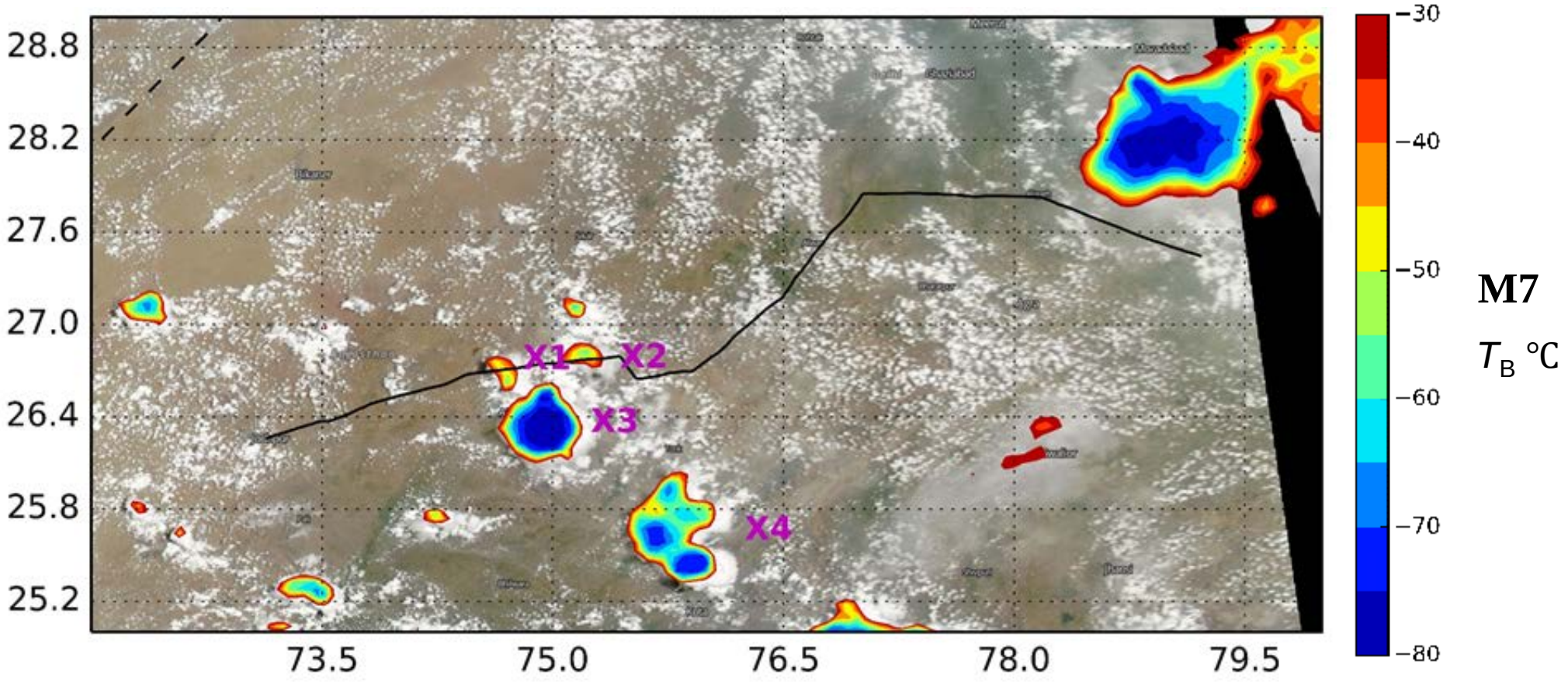
Development of post-flight clouds (afternoon)



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

Open questions:

- How general is this finding?
- How important are mesoscale soil moisture gradients in initiating monsoon convection?

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Courtesy: Emma Barton/Chris Taylor CEH

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Example emerging finding from aircraft survey

FLIGHT CASE STUDY: CONTROLS ON OROGRAPHIC PRECIP.

Jennifer Fletcher *et al.* (*QJRMS*, published online)

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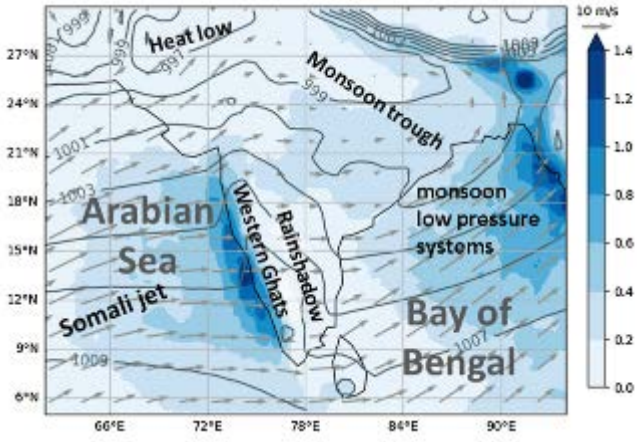
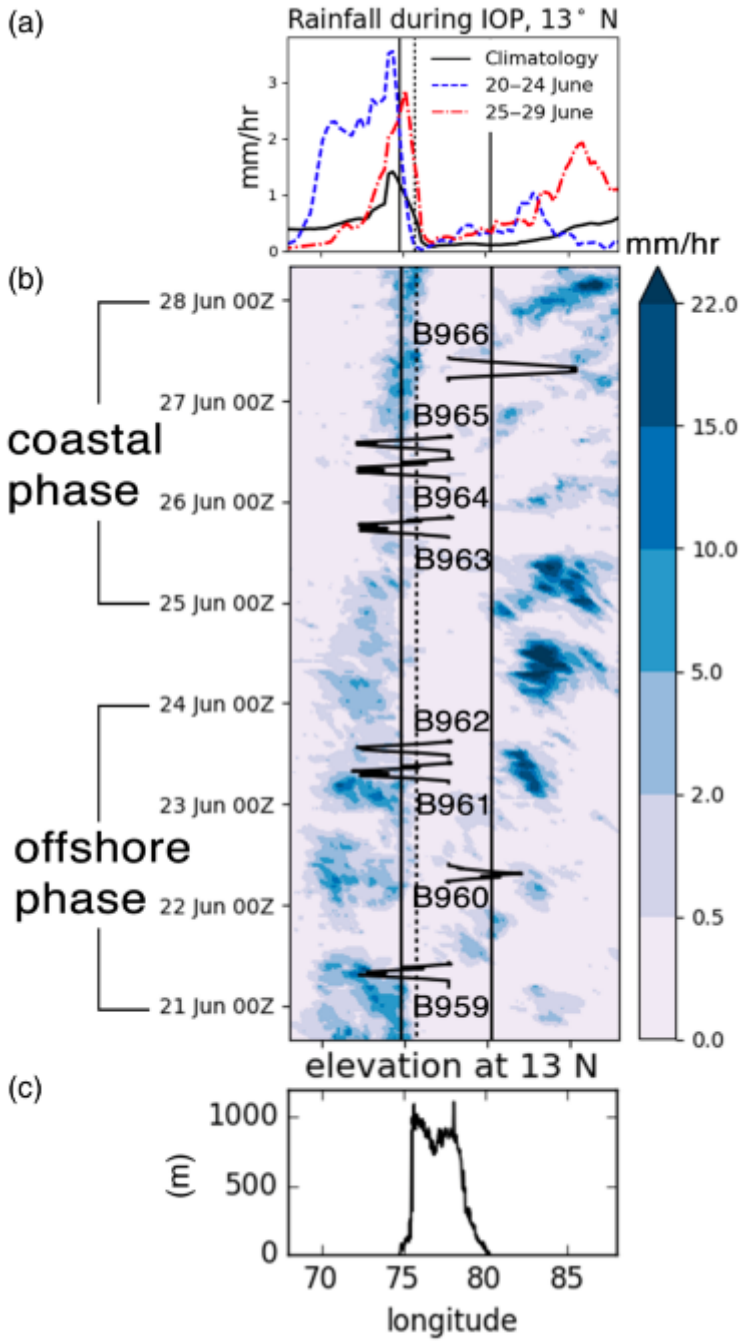
Controls on orographic precipitation



- Large amounts of rain fall over India's Western Ghats mountains (up to 2 metres per summer in places)
- INCOMPASS spent a week flying over the Western Ghats from Bengaluru
- During this week, distinct onshore (coastal) & offshore regimes of convection were observed



The dynamic and thermodynamic structure of the monsoon over southern India: New observations from the INCOMPASS IOP. J. Fletcher *et al.* (2019). *QJRMS*, in press. DOI:10.1002/qj.3439

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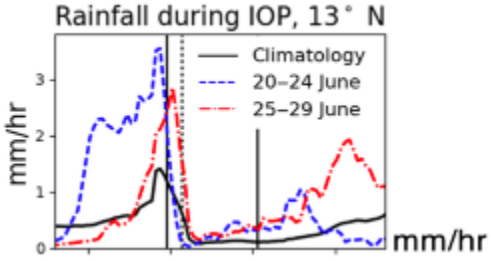
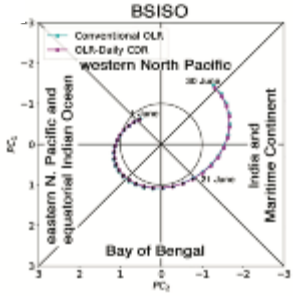
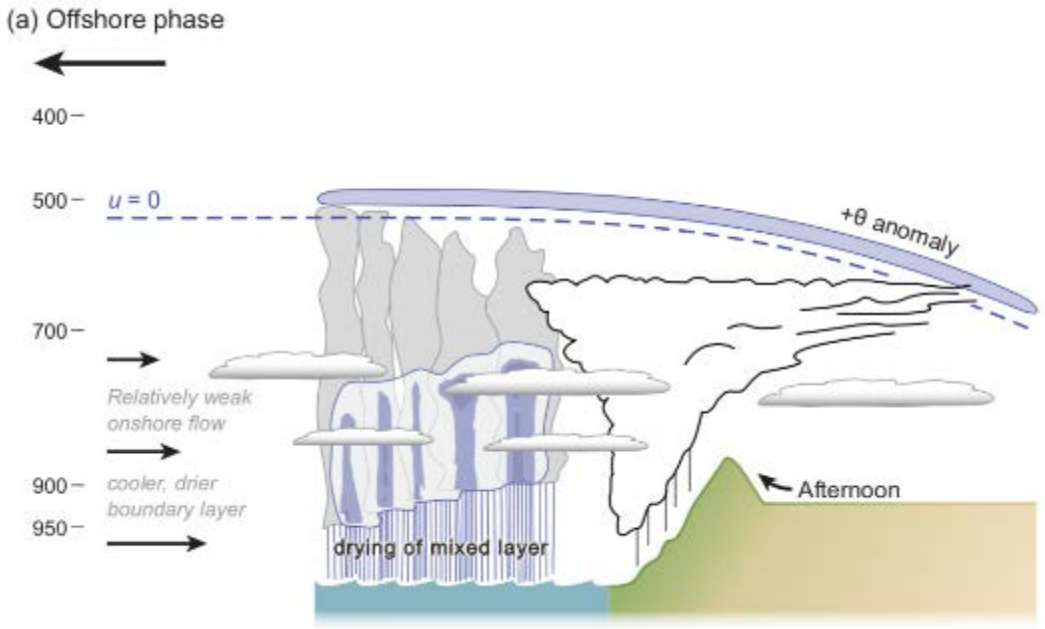
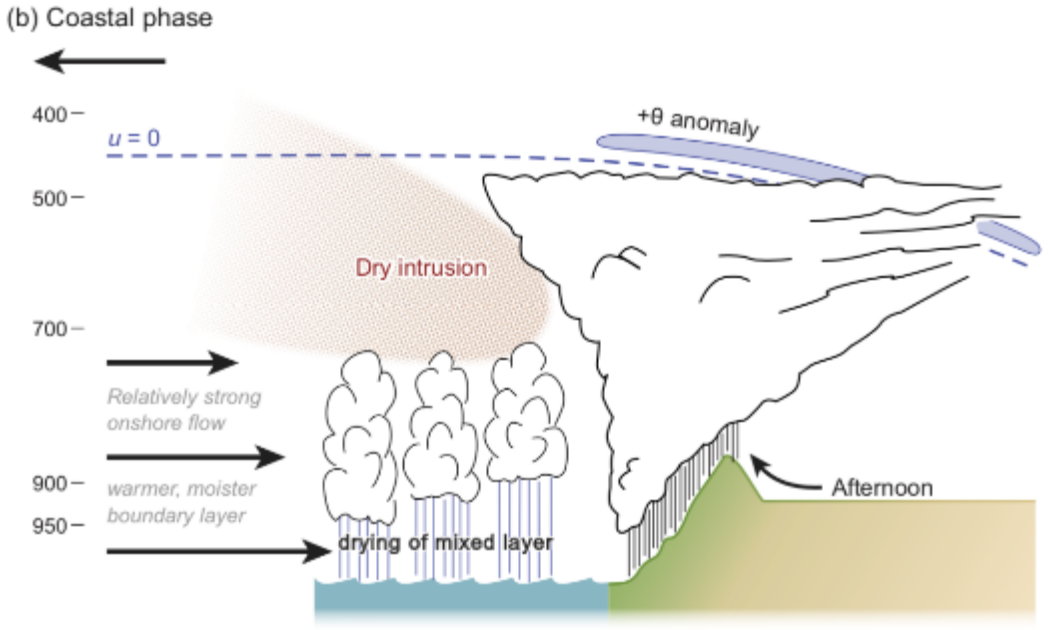
Controls on orographic precipitation





- The large scale suggests distinct differences between offshore & coastal phases of convection
- Coastal phase: Strong monsoon flow is accompanied by a mid-level dry intrusion that caps the offshore convection
- Initial analysis suggests a relationship with the BSISO (MJO)
- *Open question*: how does the BSISO (MJO) interact with dry air intrusions in controlling Western Ghats rainfall?





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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

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Thank you!

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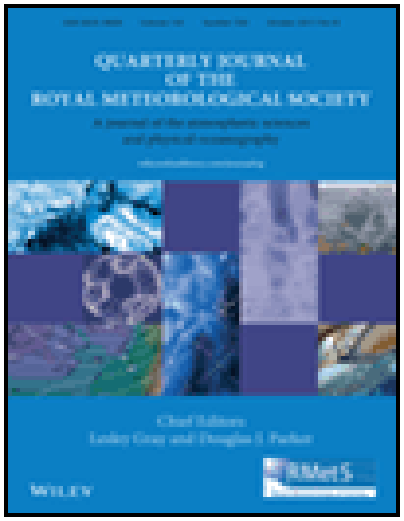

- Most data is already publicly available:
  - FAAM aircraft data via CEDA (www.ceda.ac.uk)
  - Flux tower data via EIDC (eidc.ceh.ac.uk)
- A special collection of *QJRMS* is being prepared, with some works already in press:
  - Barton, E. *et al.* (2019) A case study of land-atmosphere coupling during monsoon onset in northern India doi:10.1002/qj.3538
  - Fletcher, J. K. *et al.* (2019) The dynamic and thermodynamic structure of the monsoon over southern India: New observations from the INCOMPASS IOP doi:10.1002/qj.3439

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