Outline

• What the monsoon means for the people of India
• Basic science of the monsoon
• History of the UK’s interest in the Indian monsoon
• Monsoon weather
• Challenges of climate change for India
Some basic facts

- 1.13 billion people - one-sixth of the world's population - live in a country one-third the size of the U.S. Over 37% live below the poverty line.
- Population projected to rise to 1.8 billion by 2050.
- World’s eleventh largest economy and second most rapidly growing economy with GDP growth rate last year of 6.7%.
- Sustained by annual rainfall of around 1100mm, 80% of which arrives in the summer.
- Agriculture accounts for nearly 20% of the GDP and employs over 50% of the total workforce.
- 60% of agricultural production is rainfed and hence vulnerable.
Many states in state of worry over late rains

A farmer shows the state of his paddy that has dried up due to insufficient rain and water supply in Gidder village of Punjab.
What are Monsoons?

• ‘Monsoon’ means ‘season’, and describes a complete reversal of wind regimes during the seasonal cycle. Monsoons are characterised by a pronounced rainy season.

• Monsoons are driven by changes in the distribution of heating driven primarily by the seasonal cycle of the sun. A thermal contrast between land and sea is required to set up a monsoon.

• In winter, the wind blows from the cold land over the warm sea. In summer, the warm land pulls in the wind from the ocean like a massive sea breeze.

• Once established, the positive feedback between the circulation and latent heat release in the rain clouds maintains the monsoon
Winds near the surface (925hPa)

Winter
Summer

Asian Monsoon is part of a much larger circulation, the Asian Monsoon

Indian Monsoon
Mountains and Monsoons

- Tibetan Plateau and the Asian Summer Monsoon
- East African Highlands and the Indian Summer Monsoon
- Andes and the South American Monsoon
- Sierra Madre and the North American Monsoon
Mean Temperature in the Upper Troposphere (500 – 200mb)

Winter

Summer
Seasonal evolution of North-South gradient in 200-500hPa temperature
Climatological Onset Dates

Monsoon sweeps north and west

15 July
1 July
15 June
10 June
5 June
1 June
Snow-monsoon interactions

Model Sensitivity Study: No Snow versus Heavy Snow

~2week delay to monsoon onset in heavy Himalayan snow case

- Troospheric temperature gradient (°C)
- Apr-1 May-1 Jun-1 Jul-1 Aug-1 Sep-1 Oct-1 Nov-1 Dec-1

Turner & Slingo 2010
East African Highlands, Somali Jet and Indian Summer Monsoon
Impact of E. African Highlands on Asian Summer Monsoon

850 hPa winds

- JJA: W/out Highlands
- JJA: With Highlands
- JJA: Impact of Highlands

Rainfall

- JJA: W/out Highlands
- JJA: With Highlands
- JJA: Impact of Highlands

Slingo et al 2004
Long-Term Stability of the Indian Summer Monsoon

Mean (R) = 84.6 cm
Standard Deviation (S) = 7.9 cm
UK’s fascination with the meteorology of India

• India was Britain’s most important imperial and economic possession. By the late 1860s India absorbed 1/5th of all British exports, so its economic importance was profound.

• India appeared to offer an ideal natural laboratory for the science, and an ideal space in which to demonstrate the political importance of science in a global age.

Reference: Predicting the Weather: Victorians and the Science of Meteorology by Katharine Anderson
Henry Francis Blanford
1st British Director (Imperial Meteorological Reporter) of the Indian Meteorological Department (1875-1889)

‘Order and regularity are as prominent characteristics of our (India’s) atmospheric phenomena, as are caprice and uncertainty those of their European counterparts.’
Blanford argued that India offered a special situation for the study of meteorology:

‘We are in the position of a commander who can find no eminence from which he may gain a bird’s eye view of the combat.

Could we but find some isolated tract of mountain, plain and ocean … girdled round by a giant mountain chain that should completely shut in and isolate some millions of square miles of the atmosphere, resting on a surface vast and varied enough to exhibit within itself all those contrasts of desert and forest, of plain, plateau and mountain ridge, of continent and sea, then the progress of meteorology would be assured.’
From ‘The Indian Charivari’ – India’s equivalent of ‘Punch’: July 23, 1875
Long-Term Stability of the Indian Summer Monsoon

Mean (R) = 84.6 cm
Standard Deviation (S) = 7.9 cm
Great Famine of 1877/78: Conjunction of Politics and Science

The Indian economy was single-mindedly focused on its grain harvests.

Indian taxes to administer the country and pay dividends to its investors depended entirely on the monsoon rains.

Control of famine through climate prediction would mean that India could be governed more effectively.

"Disputed Empire": Cartoon from Punch, 1877
Sir Gilbert Thomas Walker
3rd British Director (Director General of Observatories) of the Indian Meteorological Department (1904-1924)

Pioneered statistical forecasting - formed a 'human computer' with Indian staff performing a mass of statistical correlations using data from around the world.

‘I think that the relationships of world weather are so complex that our only chance of explaining them is to accumulate the facts empirically.’

Introduced the terms Southern Oscillation, North Atlantic Oscillation, and North Pacific Oscillation.
El Niño, Southern Oscillation and the Walker Circulation
All-India Summer Monsoon Rainfall, 1871-2003

(Based on IITM Homogeneous Indian Monthly Rainfall Data Set)

© Rupa Kumar Kolli, IITM, Pune, India (April 23, 2004)
Decadal Variations in Indian Monsoon and El Nino

Updated from Slingo (1999)
Possible Players in Monsoon Variability 
(++++ Level of confidence/knowledge)

- El Nino/Southern Oscillation (++++)
- Eurasian and Himalayan snow amounts (+)
- Indian Ocean sea surface temperatures and heat content (+)
- Intra-seasonal variability e.g. active/break cycles (++)
Diversity of All-India Daily Rainfall

- What weather patterns are linked to daily rainfall variability?
- How predictable are they and on what lead times?
- How do they influence seasonal mean rainfall?
- What will happen under global warming?
July 2002: Drought in India

WHAT’S WRONG WITH THE WEATHER

- Monsoon failure leads to drought in two-thirds of India
- Eastern Bihar gets twice the average rainfall causing floods
- Rising temperatures are drying the source of the Ganga

Many states in state of worry over late rains

A farmer shows the state of his paddy that has dried up due to insufficient rain and water supply in Gidder village of Punjab.
Active-break cycles of the Indian Summer Monsoon

Northward and eastward propagation associated with the Madden Julian Oscillation (MJO)

Courtesy; Peter Webster
MJO implicated in monsoon 2009

Major failure of monsoon rains: 23% below normal
Air-sea interaction and the MJO

 Courtesy: Pete Inness
High Frequency Sea Surface Temperatures drive stronger active-break cycles

Klingaman et al. (2008)
The importance of interactive upper-ocean thermodynamics for monsoon active-break cycles

Lag correlations of intra-seasonally (30-50 day) filtered July and August rainfall

- b. HadKPP with 1 m resolution and 3 hr coupling
- c. HadKPP with 1 m resolution and 24 hr coupling
- d. HadKPP with 10 m resolution and 24 hr coupling
Mumbai flooding: July 26 2005
942 mm (37 inches) of rain in 24 hours
Changing nature of Indian rainfall (R)

(A) Number (N) of heavy (R > 100 mm/day, bold line) and moderate (5 < R < 100 mm/day, thin line) daily rain events

(B) Number (N) of very heavy events (R > 150 mm/day) during the summer monsoon season over Central India.

From Goswami et al. 2006, Science
Indian Summer Monsoon is remarkably stable:
High societal vulnerability to small changes.

India is developing rapidly: Will there be enough water to sustain that development?
The Scientific Challenges

- How will the mean monsoon behave?
- How will climate change affect the stability of the monsoon?
  - Will it become more variable?
  - Will it be less predictable?
- What will climate change mean for extreme events?
- How will changes in atmospheric composition affect the monsoon?
IPCC 4th Assessment Report: Projections of likely shifts in rainfall patterns by 2080

% change in rainfall by end of 21st century, where more than 2/3 of the models agree on the sign of the change.
Mean Annual Cycles of All-India Rainfall and Temperature for end of 21\textsuperscript{st} century

- Current
- A2: High Emissions
- B2: Low Emissions
Changes in rainfall during active and break phases

Active spells

Break spells

Monsoon breaks may become more severe – impacts on agriculture
Changing nature of Indian rainfall with climate change:
Impact of 2xCO2 on number of rain days and rainfall intensity

- Decrease in number of rain days
- Increase in rain intensity on days when raining

From: Turner & Slingo 2008
Changes in the intensity of extreme Indian daily rainfall with climate change

From: Turner & Slingo 2008
But not all models agree with this simple hypothesis…….
Impact of aerosols on the monsoon
Pre-monsoon build up of absorbing aerosol from Arabian and Saharan dust, Thar dust and local black carbon sources.

Aerosol is not all washed out during monsoon: gaps in rainfall allow burden to build up.

Lau et al., GEWEX News 18, #1
Concluding Remarks

• Much still to learn about what controls the monsoon and its variability
• Model improvements are vital for making progress in monsoon prediction
• Impacts of climate change remain hugely uncertain for those reasons
• 2010: Normal (98%) predicted by Indian Meteorological Department
Tropical Cyclone Gonu:
4 June 2007